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Vol. 244 OCTOBER, 1947 No. 4

# MAGNETIC AMPLIFIER CIRCUITS NEUTRAL TYPE

BY

ALAN S. FITZGERALD.

## GENERAL.

All of the circuits described below refer to magnetic amplifiers of the neutral type. That is to say, their response is independent of the polarity of the DC input. For example, if the output of the amplifier is used to energize a relay, the latter will be operated in exactly the same manner by a given DC input current irrespective of the direction of flow of this current.

Magnetic amplifiers which respond selectively in accordance with the polarity of the input current will be dealt with in a further paper referring specifically to amplifiers of the polarized type.

The use of the direct-current excited saturating reactor as a control device dates back at least to the beginning of the present century,[1,2] and much activity has been manifested in the invention and development of responsive and control circuits featuring this device.[3]

The development, in 1925, of the copper oxide rectifier by Dr. Grondahl has very greatly increased the possibilities of saturating reactor circuit arrangements.

Considering the resourcefulness and diligence which have been applied to these efforts, it is remarkable how few of these ingenious schemes have found a permanent place in general engineering practice. With the exception of a few large theatre stage-lighting control systems, there is no application of saturating reactors in common use with regard to which information can readily be found in technical literature.

[1] Lahmeyer, German patent No. 148,791, 1903.

[2] Burgess and Frankenfield, U. S. Patent No. 720,884, 1903.

[3] "Direct-current Control Reactor." *Electric Journal*, *28*: 561–3 (1931).

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

Because of this, little information regarding the general characteristics of the saturating reactor is available to engineers other than those occupied in development and research activities. For example, the Standard Handbook for Electrical Engineers devotes only one brief paragraph to this subject. Thus, the following outline of saturating reactor principles, while it doubtless represents matter familiar to specialists, may be a convenience to others.

### SATURATING REACTORS.

A saturating reactor consists essentially of two magnetic circuits, one subjected to an AC MMF and the other to a DC MMF. These magnetic circuits are super-imposed in such a way that a portion of the core is common to both of them.

There are a number of different types of magnetic core construction which may be used for providing saturating reactor action. These all comprise the following essential features: a magnetic circuit carries a winding which is connected to an alternating source in series with a load circuit or work device; or in some other manner the impedance of the AC winding is arranged to control the energization of the load circuit. The magnetic circuit also carries a second winding which can be energized with direct current so as to apply uni-directional excitation to the core.

When no direct current ampere-turns are applied, the alternating current winding acts exactly as the primary of a transformer which has its secondary open, or as a chokecoil having no air gap. Since the core has a high permeability, the magnetic circuit has a low reluctance and the AC winding draws a small magnetizing current which flows in the load circuit. In other words, the AC winding represents a relatively high series impedance.

When a direct current is caused to flow in the second winding, the core is subjected to uni-directional magnetization so that the flux density of the iron core may be raised to saturation point or beyond. The permeability of the core is now greatly reduced and the reluctance of the magnetic circuit is substantially increased. Thus in order to produce a flux sufficient to set up the proper counter-EMF a greater magnetizing current flows. This increases the energization of the load circuit accordingly.

Unless the saturating direct current is derived from a constant current source having a very high resistance—an unusual condition which we may disregard in considering generally applicable methods—the core structure of the saturating reactor must be so arranged that there shall be no inductive coupling between the DC and the AC windings. Otherwise the DC saturating circuit, including the saturating winding and the source of direct current, may constitute a closed path in which secondary current may be induced by transformer action. This would

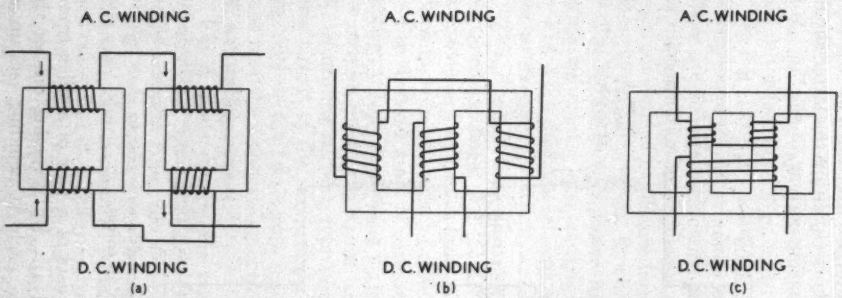


FIG. 1. Types of saturating reactor. AC windings connected in series.

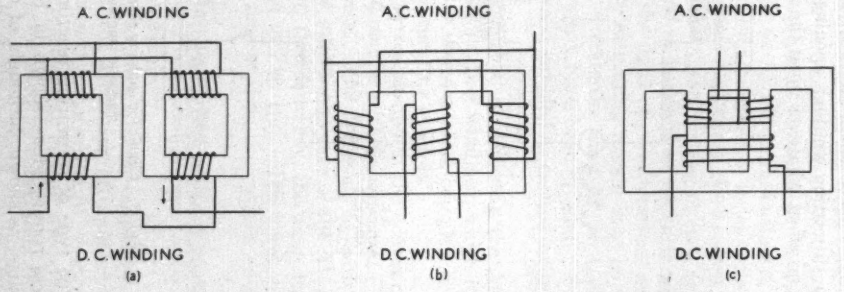


FIG. 2. Types of saturating reactor. AC windings connected in parallel.

cause an increase in the primary current and therefore a corresponding increase in the energization of the load circuit. In a properly designed saturating reactor there should be no AC EMF picked up in the DC winding by transformer action from the AC windings, disregarding harmonic effects which are dealt with later. Thus, when no DC flows in the saturating winding, opening or short-circuiting the latter should have no effect whatever upon the alternating current.

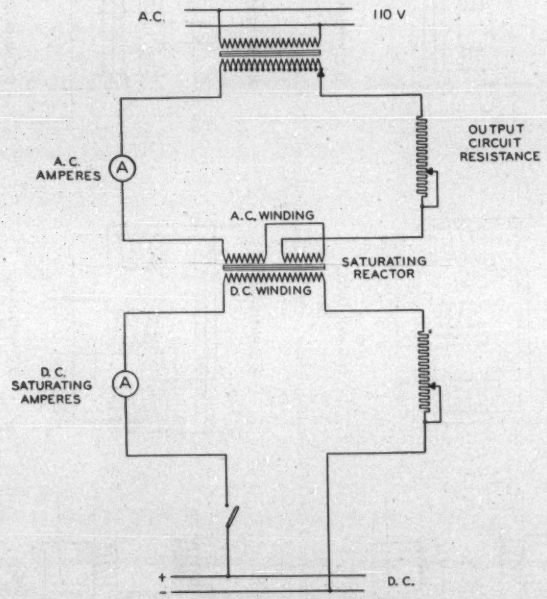


FIG. 3. Circuit for studying characteristics of saturating reactor as a magnetic amplifier with AC output.

One type of saturating reactor consists of a pair of similar transformers connected as shown in Fig. 1(a). By reversing one of the windings, as shown, although, of course, each AC winding sets up an AC secondary voltage in one of the DC windings, these voltages, if the two cores are both alike and are carefully stacked so as to be exactly similar magnetically, are equal and opposite in phase so that there is no *net* transformer action between the AC and DC circuits.

Another form is shown in Fig. 1(b). The core is of three-legged shape. The DC winding is on the middle leg and the two AC windings

are situated on the outer legs. No AC magneto-motive force is applied to the middle leg and no AC voltage is induced in the single DC winding.

Another well-known type of core is the four-legged shape shown in Fig. 1(c). The AC coils are placed on the inner legs and surrounded by the single DC winding. AC flux is set up only in the inner legs. DC magnetization exists in both the inner and outer legs. If the polarity of the AC windings is such as to give opposite directions of AC excitation in the two inner legs, there will be no AC induction in the DC coil.

In Fig. 1 the AC windings are shown connected in series. Parallel connection of the AC windings as shown in Fig. 2 may also be employed. There are definite restrictions and advantages attaching to each type of core construction and to each method of connection, which it will be more convenient to discuss later in the light of considerations arising from the specific circuits in which the saturating reactor is to be used.

The arrangements shown in Fig. 1 comprise most of the types of saturating reactor core construction which have been devised.

Fig. 3 is a diagram of connections of a simple DC excited saturating reactor circuit.

This diagram also illustrates the method of depicting the AC, or reactance windings, and the DC, or saturating windings, which it will be convenient to use in later diagrams showing more complex circuits which include a number of different saturating reactors.

Fig. 4 shows a set of saturation curves, plotted in the conventional manner, taken on a typical saturating reactor with the set-up of Fig. 3, the output circuit resistance being zero. The upper curve, with zero DC saturating current, represents the saturation curve of the AC magnetic circuit of the saturating reactor, that is to say, the outer legs in Fig. 1(b) or the two center legs only, in Fig. 1(c). The lower curves show how the magnetizing current is increased by the various values of DC saturating current.

Fig. 5 shows exactly the same relations plotted with the ordinates and abscissae transposed since this aspect is somewhat more convenient, the AC current being the dependent variable.

Fig. 6 shows the same data plotted to show how the output current, with zero load resistance, varies with the saturating or input current, each curve in Fig. 6 referring to a different value of the AC voltage.

The way in which the saturating reactor may control the power in the output circuit can most readily be followed by considering the AC winding of the reactor as a variable impedance which can be changed at will from a high value, which obtains when the DC saturating current is zero, to a lower value which it represents when DC saturating current is applied.

Thus the current flowing in the AC winding of the reactor increases from a relatively low value when there is no DC input, to a higher value when DC input is applied.

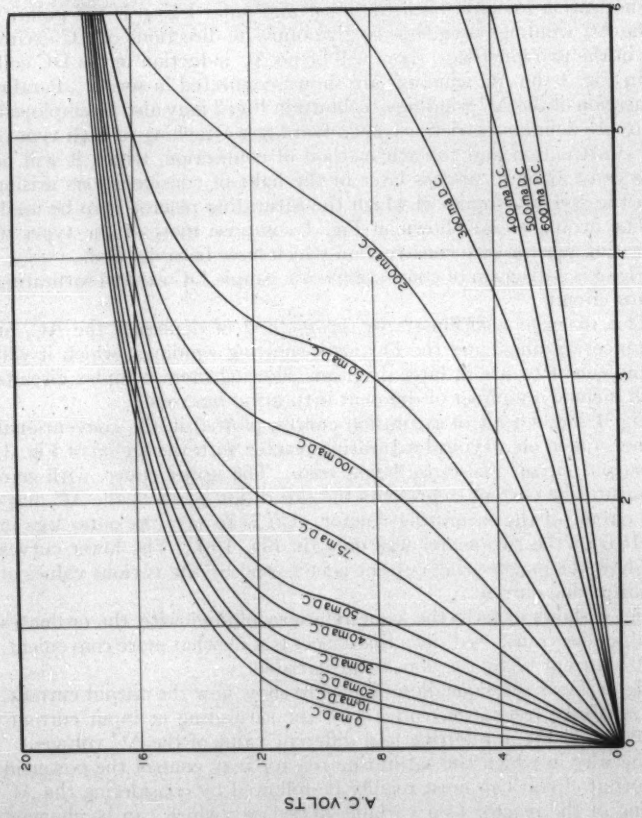


FIG. 4. Saturation curves of reactor for different values of direct current.

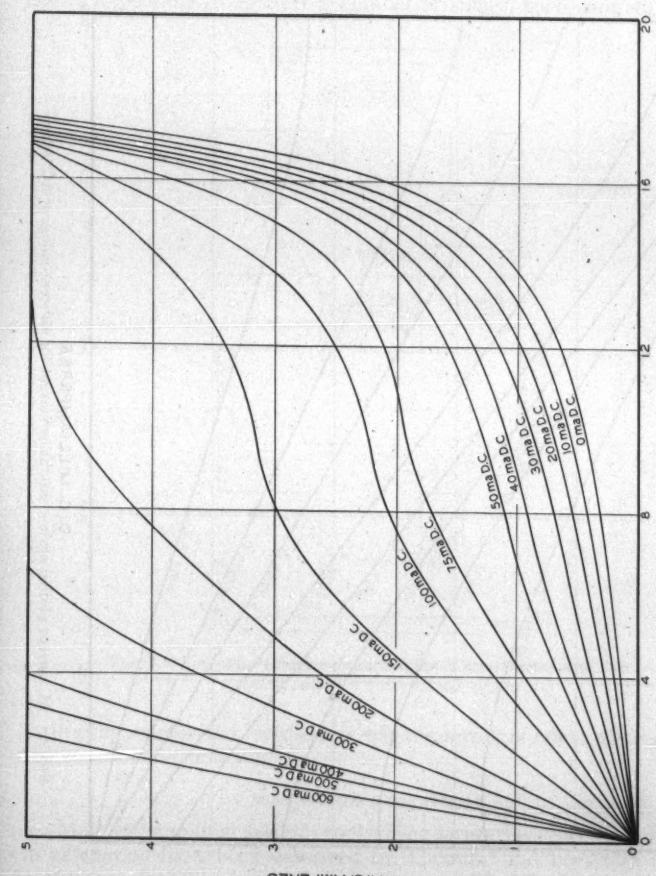


FIG. 5. Saturation curves of reactor for different values of direct current, plotted with alternating current as ordinates.

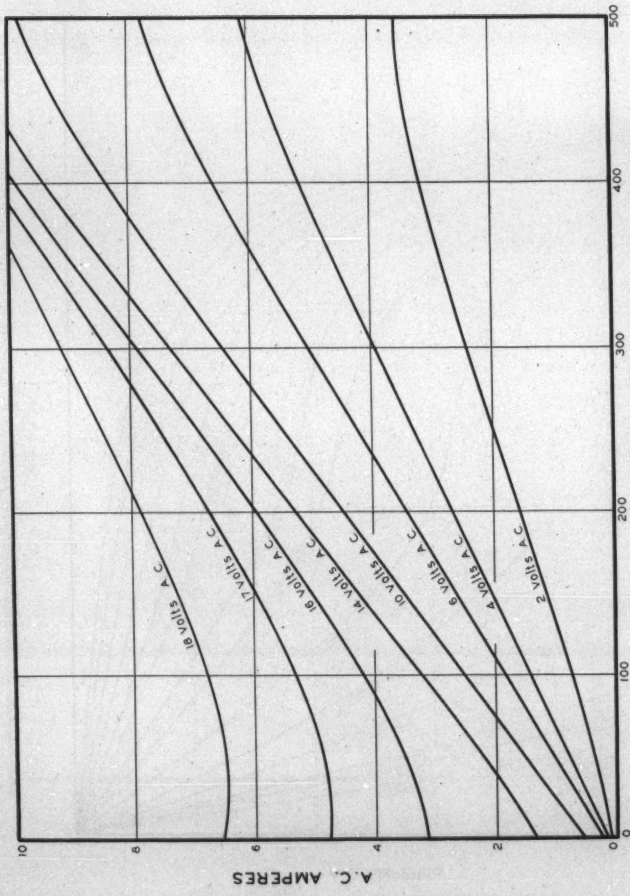


FIG. 6. AC current plotted against saturating current for different values of AC voltage.

In the arrangement shown in Fig. 3, it will be noted that the input is DC, but the output, that is to say, the current which is varied or controlled, is alternating. This alternating current output may be rectified as shown in Fig. 7 so that both input and output are now DC. This makes it possible to connect a number of stages, each consisting of a

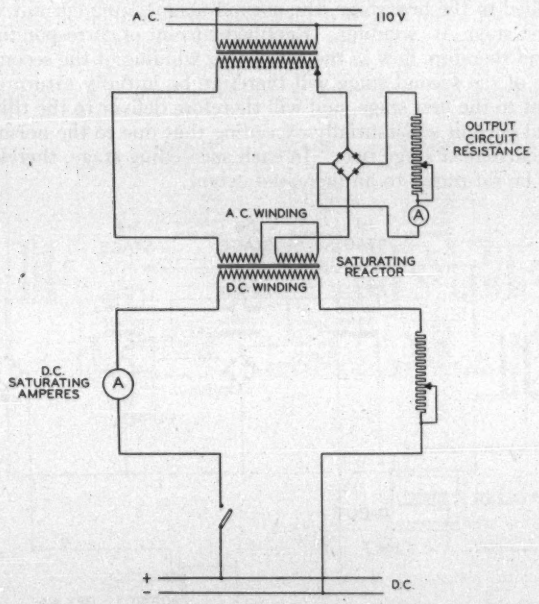


FIG. 7. Circuit for studying characteristics of saturating reactor as a magnetic amplifier with rectified output.

saturating reactor and rectifier, so that the output of one stage feeds into the input of the next stage.

### MULTIPLE STAGE CONNECTION.

Magnetic amplifier systems comprising saturating reactors connected in catenation have been described by Thomas [4] and Lee.[5] In the arrangement described by the former, illustrated in Fig. 8, the current in the AC winding of the first stage is connected to energize a rectifier and the rectified current is used to apply saturating excitation to the second

[4] U. S. Patent No. 1,730,254.
[5] U. S. Patent No. 1,855,639, Reissue 19,129.

stage. The third stage, in like manner, is saturated by the output of the second stage. A relay is operated by rectified current from the third and last stage.

There is, however, a difficulty, recognized by Lee, in respect of the arrangement shown in Fig. 8, which must not be overlooked. This arises from the fact that, even when there is no input or saturating current applied to the first stage, the normal magnetizing current will flow in the first stage AC winding. Rectified current of corresponding magnitude will therefore flow in the saturating winding of the second stage. The core of the second stage will therefore be initially saturated, with zero input to the first stage, and will therefore deliver to the third stage a rectified current substantially exceeding that due to the normal magnetizing current of stage two. In each succeeding stage, therefore, the core will be saturated to an increased extent.

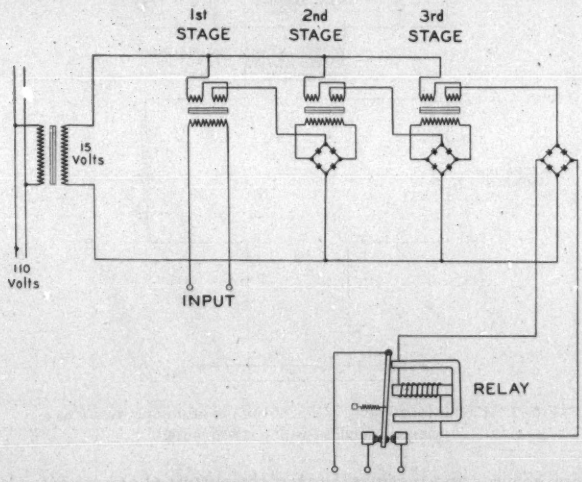


FIG. 8. Three-stage cascade arrangement.

It is obvious, therefore, that this very materially limits the usefulness of a simple catenated arrangement. Apart from the loss of gain in all but the input stage, it will be noted that this circumstance sets a definite limit to the number of stages which may be employed. If more than two or three additional stages are connected the output stage will become fully saturated by the cumulative effect of the normal magnetizing currents in the preceding stages, even though no input be applied to the first stage. Thus the system would be entirely ineffective.

The principle used by Lee is shown in Fig. 9. In each stage a dummy or counter-poise reactor is employed. The counter-poise has no direct current winding, but should have the same alternating current magnetic characteristics as the saturating reactor which receives the direct current input. The circuit is arranged so that only the difference between the currents flowing in the counter-poise and saturating reactor AC windings is delivered by the circuit to the input of the next stage.

This result is obtained by the use of a differential transformer having two similar primary windings, which carry, in opposite sense, the counter-poise and saturating reactor AC current. The transformer core

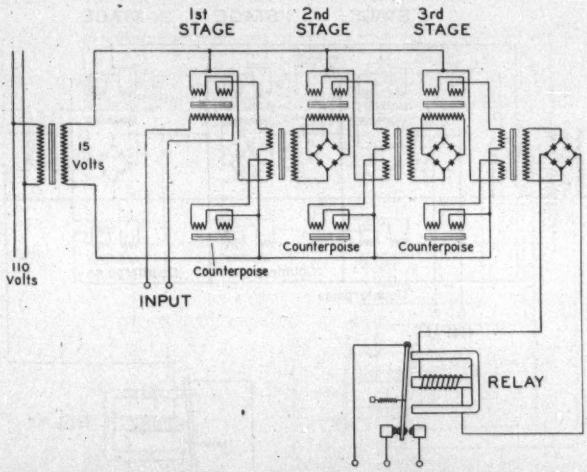


FIG. 9. Compensation by means of counterpoise and inter-stage transformer.

is therefore magnetized only in accordance with the difference between these currents.

Thus, when there is no DC input to the saturating reactor, the transformer secondary voltage is zero and no rectified current flows in the input winding of the next stage.

Fig. 10 shows another method along somewhat the same lines, used by the author,[6] for achieving the same result.

As in Fig. 9 a counter-poise is used for each saturating reactor. A transformer having a secondary mid-point tap is energized from the AC source. The rectifier is connected between the mid-point tap and the junction of the AC windings of the counter-poise and saturating reactor. With this arrangement when there is no DC input the impedance of the

[6] U. S. Patent 2,027,311.

saturating reactor AC winding is exactly the same as that of the counterpoise. Thus the junction between these two windings, and the mid-tap on the transformer, are equipotential points. No AC voltage is therefore applied to the rectifier and no rectified current flows in the input of the next stage.

This problem has been solved by the author [7] in a different manner by the circuit shown in Fig. 11.

This diagram also shows a three stage magnetic amplifier in which the rectified output of the first stage flows in the saturating winding of

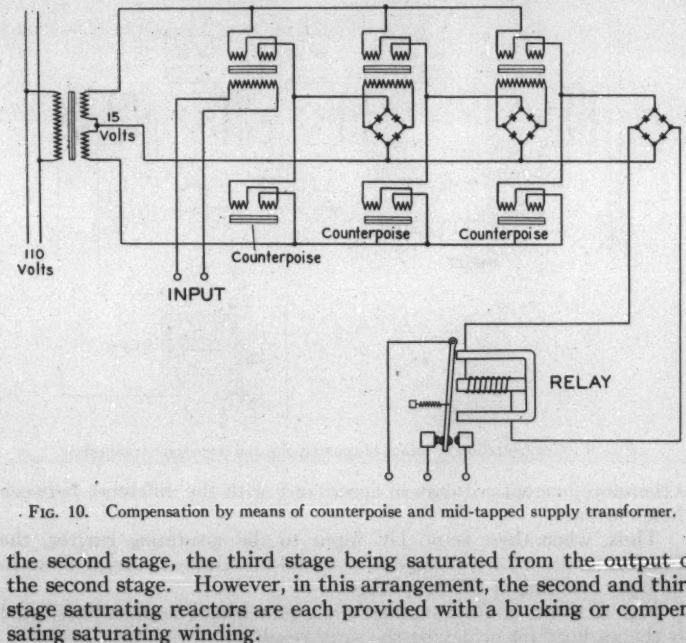


FIG. 10. Compensation by means of counterpoise and mid-tapped supply transformer.

the second stage, the third stage being saturated from the output of the second stage. However, in this arrangement, the second and third stage saturating reactors are each provided with a bucking or compensating saturating winding.

Each of these windings is energized from an additional rectifier and the compensating current is set to the proper value by means of the adjustable resistors shown in the diagram. These compensating windings, as indicated, are connected so that their magnetizing effect is in opposition to the action of the saturating windings, so as to compensate

[7] U. S. Patent 2,027,311.

for the normal magnetizing current which flows in the AC windings of the reactors when no saturating effect is applied. Thus the rheostat which controls the compensating current in stage two may be adjusted so that the compensating ampere-turns are exactly equal and opposite to those of the saturating winding of stage two, due to the magnetizing current of stage one, when no input or saturating current flows in the input winding of stage one. This adjustment is readily made by observing the rectified current which flows in the saturating winding of stage three, there being no input to stage one, and adjusting the stage two rheostat so that this current is a minimum.

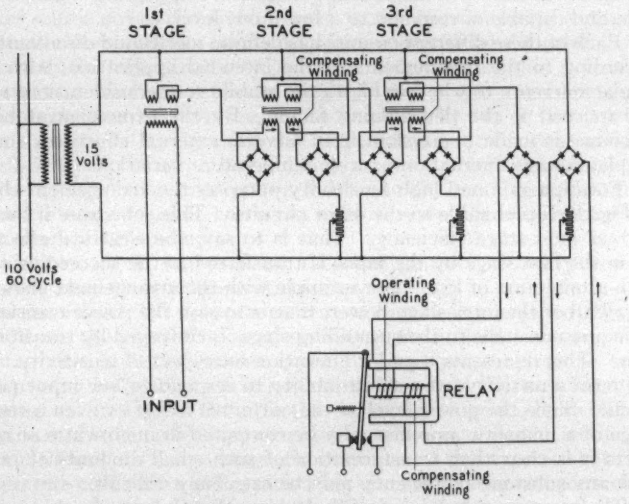


FIG. 11. Compensation by means of bucking DC winding.

Precisely similar adjustment is made for the third stage. The rheostat controlling the compensating current in stage three is set so that the current in the operating coil of the relay is a minimum. It is important, however, to note that this adjustment, at the second stage, should only be made when there is no current flowing in the saturating winding of the input stage. Furthermore, the compensating current in the third stage can only be properly adjusted if the compensation in the preceding stage has been correctly set. It will be seen that under these conditions when there is no input to stage one, the cores of all of the three reactors will be completely unsaturated. Thus the saturating effect on each stage tends to be directly proportional to the input.

It will, however, be noted, that, with complete compensation as described, so that no saturating ampere-turns are applied to stage three, there will still be some magnetizing current in the last stage, so that commensurate rectified current will flow in the operating coil of the relay. As shown in Fig. 11 a similar compensating winding is embodied in the relay. The relay compensation is adjusted so that with no input and with correct compensation adjustment in stages two and three, no pull at all can be felt when the armature of the relay is closed by hand.

Some arrangement for compensating for the magnetizing current that flows in a saturating reactor when there is no input is essential to the achievement of a multi-stage magnetic amplifier of high over-all gain and capable of response to a low input level.

Each of these different circuits has definite merits and disadvantages according to the requirements of the intended application, with particular reference to whether high gain, stability, or considerations relating to cost, is the determining factor. By the expression stability, reference is made to freedom from adverse external effects as, for example, voltage fluctuation or wide temperature variations.

For high gain and high sensitivity purposes the arrangement shown in Fig. 11 is preferable to the other circuits. This is because it has the highest inter-stage efficiency. That is to say, the electrical effect set up in the first stage by the input is transferred to the succeeding stage with a minimum of loss. For example with the arrangement shown in Fig. 9 all of the inter-stage power, that is to say, the power transferred from any one stage to the succeeding stage, is conveyed by transformation. This represents a major limitation in respect of sensitivity. By the term sensitivity, we refer to ability to respond to low input power levels. Since the power level at the output of a first or even a second stage of a magnetic amplifier may be computed in microwatts or milliwatts it is clear that transformation of such small amounts of power with any substantial efficiency may be extremely difficult.

The arrangement shown in Fig. 10 is somewhat better in this respect in that the transformer used in this circuit is energized from the source and not exclusively by the inter-stage power.

In the arrangement shown in Fig. 11, on the other hand, the whole of the power increment developed in the first stage is conveyed to the succeeding stage without loss except rectification, which loss is common to all of the circuit arrangements described. The method by means of which compensation is furnished for the current which flows when there is no DC current in the input winding, makes use of additional power drawn directly from the source. The compensating winding excitation is not inter-stage power. This power is derived directly from the AC supply. It is not subtracted from the power delivered from the first stage to the second stage. There is only one way in which the presence

of the compensating winding constitutes any reduction whatever in the excitation applied to the second stage by the first stage.

Suppose we consider the effect of the application of a power level of given magnitude to a magnetic amplifier stage. If the stage in question is the first stage, having no compensating winding, the excitation set up will be in accordance with the ampere-turns resulting from the physical constants of the input winding, namely the number of turns and the resistance. If the stage is not the first stage and has a compensating winding the only effect upon the excitation will be that which results from a slight reduction in the space factor of the winding which receives the inter-stage excitation. Since the compensating winding receives source power it may be wound outside the saturating winding. The greater resistance per turn will have no effect upon the gain.

Actually in high sensitivity magnetic amplifiers of this type the compensating windings necessary in the earlier stages require so few ampere turns that this may readily be furnished by one or two layers. The space occupied by these few outer layers does not reduce the excitation efficiency of the saturating winding to any appreciable extent.

Where high inter-stage power levels obtain, more compensating ampere turns are required and more window space has to be alloted to the compensating winding.

This method of compensation therefore permits of much greater sensitivity than the arrangements of Figs. 9 or 10.

On the other hand the arrangement of Fig. 11 is inferior to Figs. 9 and 10 from the point of view of stability. Both of the counter-poise circuits, because of the balance principle employed, tend to be self-compensating for voltage variation and temperature effects. The disadvantage of the Fig. 11 circuit is that it employs a principle involving a condition of balance between currents furnished by different rectifiers. It is not difficult to design magnetic amplifiers of this type so that the temperature coefficients of the saturating circuits and the compensating circuits are substantially the same. But it is necessary to take this circumstance into consideration.

Likewise, due to the non-linear characteristics of rectifiers, there is liable to be a greater tendency for the characteristics of the amplifier to be subject to variation with wide fluctuations in the supply voltage. However constant voltage transformers are now available at no great expense.

Another advantage of the balance systems shown in Figs. 9 and 10, over the DC compensating winding method, relates to the output circuit arrangements. While the provision of the additional compensating winding on a relay is simple and inexpensive, it does not permit the use of stock types of relay. Furthermore, the compensating winding feature is not readily applicable to other types of output devices

such as motors or the like, where it is desired that the output be reduced completely to zero when there is no input.

Considering now the question of relative costs, the arrangement shown in Fig. 9 is likely to be the most expensive in that it includes the greatest amount of material. Assuming that response to low power levels is involved, high permeability core material will necessarily be involved in at least the first and second stages if not also the third.

Since the counter-poise reactor has to have the same magnetic characteristics as the saturating reactor it is likely to have an identical core. Thus, each low power level stage will require two high permeability reactor cores instead of only one as in Fig. 11.

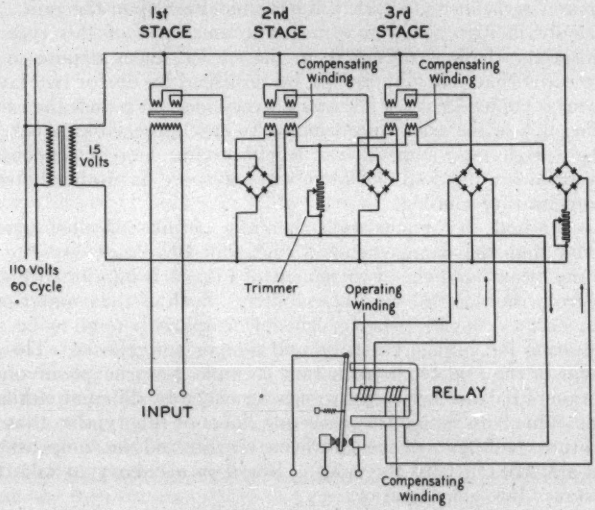


FIG. 12. Compensating DC windings supplied from single rectifier.

Moreover, since inter-stage transformation is involved, the transformer also will have to be of high permeability core material.

The Fig. 10 circuit may be expected to be slightly less expensive than the Fig. 9 arrangement since there are no inter-stage transformers. The transformer which has the mid-tapped secondary is a power transformer and will have a core of ordinary transformer iron; and only one is required.

On the other hand, the Fig. 11 circuit requires only one magnetic device in each stage.

This circuit has been shown in Fig. 11, for purposes of explanation and description, as having an individual compensating rectifier for each stage. This arrangement of individual rectifiers is very much more convenient for purposes of research, study or development, as it permits of much greater flexibility in setting up the circuit. However, it is only necessary that a single rectifier be furnished for supplying all of the compensating circuits.

Such an arrangement is shown in Fig. 12. The three compensating windings are connected in series, with suitable shunt and series resistors for making the necessary adjustments. The amount of compensating ampere-turns required for the relay is not at all critical and can be provided for with sufficient precision by calculation and provision of a suitable number of compensating turns.

Thus the type of magnetic amplifier circuit which is based upon the use of DC compensating windings has the highest sensitivity, the highest gain per stage and is the least expensive. The balance or counter-poise type or circuit has, however, inherent advantages where wide voltage fluctuations or extremes of temperature are involved, and where complete de-energization of the output circuit is necessary.

**Testing Prosthetic Devices.**—(*Mechanical Engineering*, Vol. 69, No. 5.) A new testing machine has been developed at Northwestern University that will make an artificial leg "walk" at the rate of 3,000,000 steps in ten days—the equivalent of three years of normal wear.

The machine, called a fatigue tester, will permit faster testing and development of improved artificial limbs for this country's 20,000 veterans and 65,000 war workers who have had amputations.

A 300-lb. load, one and a half times that of the average man, is shifted continually from heel to toe of the foot of the artificial leg at a rate of four complete cycles per second—which means that the leg actually is "running" as fast as the swiftest athlete. Thus the amount of punishment it would take over a period of years is concentrated into a few days or weeks.

In one test the durability of artificial leg fittings used at U. S. Army amputation centers was demonstrated when a leg with the fittings completed 7,190,000 steps, or three weeks of continuous high-speed walking, without failing. This was equivalent to seven years of normal wear, which is computed to be one million steps per year.

Knee and ankle mechanisms of light metal alloys may be the parts most susceptible to wear, as evidenced by tests of another model in which the plastic shank remained intact after 4,800,000 steps, but the metal knee cracked after 600,000 steps and metal bearings in the ankle after 410,000 steps. An experimental plastic limb now under test has undergone 5,300,000 steps without failure.

Electrical wire strain gages that translate pressure into measurable electric current are attached to various parts of the limb to record the exact pressure and tension in each part. Although the over-all load is 200 to 300 lb., some parts of the knee and ankle mechanisms are so small that pressure concentrated on them is sometimes as high as 9,600 psi. The load on other parts, tests showed, is as low as 4 psi. A major problem is to design the limbs so that pressure is more equalized.

Preliminary tests indicate that a combination of riveting and bonding (plastic cementing) is the strongest means of connecting joints and that new plastic parts show promise of great strength. No plastic part of any limb has failed yet in the fatigue-testing machine.

In addition to testing, the Northwestern research group is studying all literature and patents on artificial limbs as far back as 1863. Their findings, which will include reports on legs, hands, hooks, and harnesses, and other suspension devices, will be presented in the spring to the National Research Council's Committee on Artificial Limbs.

R. H. OPPERMANN.

# KILLING AIR-BORNE RESPIRATORY MICRO-ORGANISMS WITH GERMICIDAL ENERGY.

BY

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Disinfection or sterilization of water, milk and other materials has become accepted as a means of decreasing or preventing illnesses, contamination and spoilage. Pasteurized milk is widely accepted as far less dangerous to drink than untreated milk. Other liquids are pasteurized by heating them to kill living micro-organisms. Water supplies are treated with germicidal chemicals on a large scale by municipalities. Infection by air-borne organisms is recognized in many practices. Physicians, surgeons and nurses use masks for the prevention of infection by respiratory micro-organisms. For years it has been known that ultraviolet energy of certain wavelengths is a powerful germicide, and quartz mercury-arcs have been used to a limited extent. However, the recent advent of the low-pressure mercury-arc of greatly increased germicidal efficiency has extended the possibilities of ultraviolet energy as a germicide into realms heretofore served only by heat and chemicals. In fact, ultraviolet energy now promises to greatly extend the practice of disinfection or sterilization of air, water and other materials.

## GERMICIDAL EFFICIENCY AND EFFICACY.

This new low-pressure mercury-arc produces germicidal energy several times more efficiently than the quartz mercury-arcs which preceded it. Practically all its ultraviolet energy is emitted in the spectral region of $\lambda 2537$ which, as seen in Fig. 1, is approximately the wavelength of maximal germicidal effectiveness.[1] Nearly one-third of the total radiant energy emitted by this low-pressure mercury-arc is in the region of $\lambda 2537$. This accounts for its relatively high germicidal efficiency. It is the basis of modern fluorescent lamps. However, its tube or bulb is of clear ultraviolet-transmitting glass which is not coated with fluorescent materials. This accounts for these sources being termed *germicidal lamps*, although some have been given specific commerical names.

The killing or inactivation of micro-organisms requires time, and the dosage is measured by the product of the intensity $E$ of germicidal energy and time $t$. For the present purpose $E$ is measured in microwatts per sq. cm. and $t$ is measured in minutes. Therefore, the dosage $Et$ is expressed in microwatt-minutes per sq. cm.

Fig. 2 is presented to give an idea of the intensities $E$ in microwatts per sq. cm. at various perpendicular distances from the center of the tube of 15-watt and 30-watt germicidal lamps. In this connection it is of interest to note that a dosage, $Et$, of a few microwatt-minutes per sq. cm. can achieve a complete kill of *E. coli*, or various pathogenic organisms, and of those expelled from the respiratory organs. In fact, the dosages, $Et$, for a high percentage of kill in dry air, in humid air, in water and on the surfaces of nutrients vary from 1 to 1000 microwatt-minutes per sq. cm. for various organisms such as *E. coli*, molds and organisms on dust particles. By comparing these values with those of

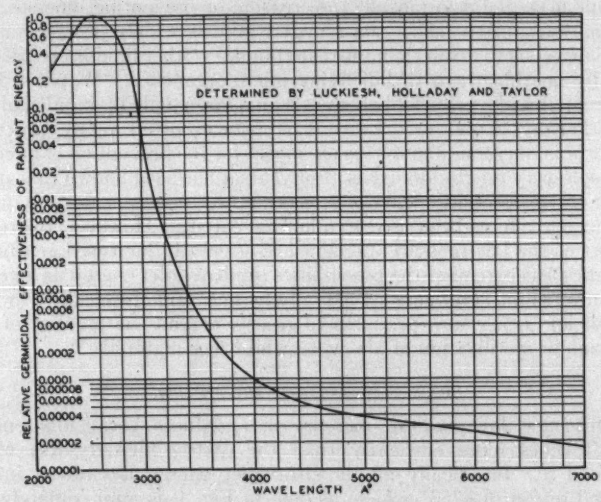


FIG. 1. The relative germicidal effectiveness of radiant energy of various wavelengths as determined for *Escherichia coli* by Luckiesh, Holladay and Taylor.[1]

$E$, in Fig. 2, at various distances from a 15-watt or 30-watt germicidal lamp, one obtains an idea of the practicability of these lamps for disinfection or sterilization. Obviously, the intensities at various distances from a given germicidal lamp can be increased by the use of an efficient reflector of properly treated aluminum. At present germicidal lamps are available in four wattages, 4, 8, 15 and 30 watts, respectively.

### DISINFECTING AIR IN OCCUPIED ROOMS.

With the advent of germicidal lamps of relatively high germicidal efficiencies, extensive applications appeared possible in the disinfection

of air for the protection of occupants of rooms from infection by respiratory micro-organisms and for the protection of products from contamination. The authors and their colleagues attacked the various problems systematically under controlled laboratory conditions.[1] Naturally, some experimenters have tried to establish the benefits of installations of germicidal lamps in occupied rooms by determining the decrease in illnesses due chiefly to air-borne pathogenic organisms. The difficulties of achieving adequate experimental control of occupants are obvious. For example, school children might be adequately protected by a germicidal installation in their classroom, but might become

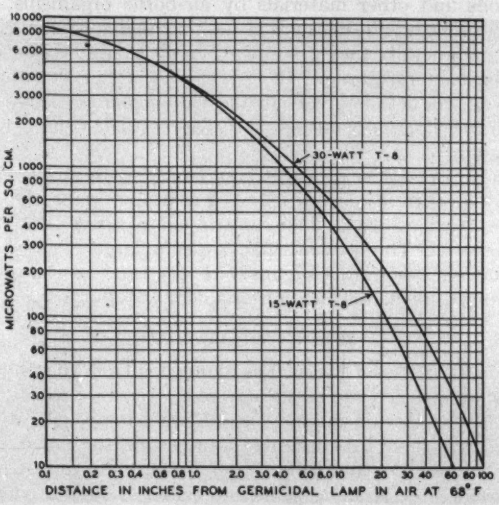


FIG. 2. The intensities of germicidal energy (λ2537) at various distances perpendicular to the middle of the tube of bare 15-watt and 30-watt germicidal lamps. One microwatt per sq. cm. equals 0.929 milliwatt per sq. ft.

infected in a school bus, theater or elsewhere. Nevertheless, promising results have been obtained in some investigations of this nature notwithstanding the inherent difficulties of control. Infections resulting from exposures outside the irradiated interiors dilute or tend to conceal the protective benefits of germicidal installations.

Various aspects of air disinfection are best investigated under laboratory conditions. In fact, the scientific foundations of technical practices are very generally established under such conditions. The practicability of disinfecting air with germicidal lamps depends upon experimental data pertaining to such questions as: What are the in-

tensities and dosages of germicidal energy necessary to kill or inactivate most or all the air-borne organisms? What are the relative resistivities of the various pathogens? What is the effect of humidity? What are the practical ways of installing germicidal lamps to disinfect the air to a desired degree? Various other questions arise such as: How long do air-borne organisms expelled from the respiratory organs live in air or on surfaces? Over what range does the reciprocity law, $Et = k$, hold? What are the threshold dosages which kill or inactivate pathogenic organisms?

Obviously, similar questions arise when considering the contamination of foods and other materials by air-borne organisms. In these cases many other organisms such as molds, mold spores and yeasts are important. Generally they are more difficult to kill or inactivate than those of the bacteria group. In any case, whether the protection of occupants or products is involved, the major goal is to free the air of the undesirable micro-organisms or to reduce their concentration to a desired degree.

The authors and their colleagues first attacked the problems by using *E. coli* under controlled conditions.[2] From this point the work was extended in various ways, including a comparative study of other micro-organisms. The present paper deals largely with organisms expelled from the respiratory organs, but also provides glimpses of basic factors involved in the disinfection of air for any purpose.

### THE RECIPROCITY LAW, $Et = k$.

Throughout various fields such as photochemistry and photobiology, the socalled reciprocity law is encountered. In other words, if a given result is due to a certain intensity of radiant energy operating over a certain period of time, it is desirable to ascertain the range over which this reciprocal relationship holds. To investigate this matter, it is necessary to measure accurately[3] the intensities of radiant energy over a large range and to vary the time so that $Et$ is of constant value. If the result, such as the killing of a certain percentage of micro-organisms, remains constant, the reciprocity law is said to hold over that range of intensities and time. The average resistivity of a given organism may vary considerably depending upon its environment. For example, *E. coli* are at least ten times as resistant in water or in very humid air as they are in relatively dry air. The resistivity of a given organism may be different in air from what it is on the moist surface of a nutrient. Therefore, the range of validity of the reciprocity law should be established for a specific organism in a specific environment. This range is usually found to be adequate for practical purposes.

[1] In Fig. 3, typical results are illustrated with staphylococcus aureus on a nutrient surface. The upper halves were not irradiated with germicidal energy. The lower halves received a dosage, $Et$, of 38.5

microwatt-minutes per sq. cm. The intensities $E$ were 350 and 0.35 microwatts per sq. cm. and the times $t$ were 0.11 and 110 minutes, respectively. Such data as those presented in Fig. 3 supply evidence that the reciprocity law in this case holds approximately over a range of 1000 to 1. It is of particular interest to note that an intensity of germicidal energy as low as 0.35 microwatt per sq. cm. is effective if it is operative for a long time. This appears to be a safe intensity for the exposure of occupants of a room for periods of 8 hours or even longer. Adequate data have been obtained for various organisms in different environments to indicate that the reciprocity law generally holds over

RECIPROCITY LAW TEST WITH STAPHYLOCOCCUS AUREUS
ON NUTRIENT SURFACE
E = 350
t = 0.11
E = 0.35
t = 110
Et = 38.5 MICROWATT-MINUTES PER SQ. CM.

FIG. 3. The range over which the reciprocity law, $Et = k$, holds is an important matter in photobiological effects. Here it is shown to hold over a range of 1000 to 1 when *Staphylococcus aureus* were exposed on a nutrient surface to energy of λ2537.

large enough ranges to encompass most practices. This fact greatly simplifies the computations necessary in theory and practice.

Incidentally, one might wonder what effect the germicidal energy would have on the nutrient in such cases as illustrated in Fig. 3. In these cases the nutrient has been subjected to very great dosages without any apparent effect upon it as a culture medium. Dosages $Et$ as great as 50,000 microwatt-minutes per sq. cm. were applied to one-half the sterile nutrient surface of petri dishes before infecting the surface. On incubation no difference in the growth of the bacteria on the two halves was noticeable. This conclusion might not apply to all nutrients,

but it is true for the nutrient we have used in obtaining data for airborne organisms presented in this paper. Unless otherwise stated, this was Tryptose Blood Agar Base (Difco) with and without adding fresh sterile blood.

### THE INFLUENCE OF HUMIDITY.

It has been adequately shown by W. F. Wells[4] and colleagues, and by the authors[1] that humidity markedly affects the resistivity of airborne organisms to germicidal radiant energy. The fact[5] that it requires at least 10 times the dosage *Et* for a complete kill of *E. coli* in a thin layer of water as it does in air of commonly low humidities indoors in the wintertime is significant in this respect. However, direct evidence is available from many experiments with *E. coli* and other organisms, including those expelled from the respiratory organs. These organisms, whose natural environment is equivalent to one of maximal humidity, are decidedly more resistant in humid air than in dry air. For example, a high degree of kill or inactivation of *E. coli* in relatively dry air is achieved by a dosage *Et* of the order of one microwatt-minute per sq. cm. The same degree of kill in air, when the relative humidity is 83 per cent., requires at least 10 times this dosage. A complete kill of *E. coli* in a thin layer of water requires about 160 microwatt-minutes per sq. cm. This is achieved in air with a relative humidity of 35 per cent. by a dosage of the order of 16 microwatt-minutes per sq. cm.

In Fig. 4 is presented some visual evidence for *E. coli* in air at relative humidities of 96 and 40 per cent., respectively. The nutrient in this case was Levine's Eosine Methylene Blue Agar and the petri dishes were exposed in our Radial Jet Air-Sampler described elsewhere.[6] Air was infected with *E. coli* and passed through a tunnel before reaching the petri dish in the sampler. While the petri dish revolved one-half revolution, the air in the tunnel was not being irradiated with germicidal energy (see Fig. 9). While the petri dish revolved the other one-half revolution, the air in the tunnel was irradiated with various intensities of germicidal energy to produce different dosages. In Fig. 4 the lower halves show the results of dosages *Et* of 3.6, 10 and 40 microwatt-minutes per sq. cm. The upper halves of the petri dishes were exposed to the same amount of the infected air without being irradiated with germicidal energy. The effect of humidity is obvious in this illustration, and it was verified by many samplings and actual counts.

The same general results were obtained with air artificially infected with micro-organisms obtained from the mouth and throat. In other words, the resistivity of these organisms, whose natural environment is one of high humidity, is markedly less in dry air than in humid air. In this connection it is interesting to note that during the winter months in climates requiring artificial heating of interiors, the relative humidities indoors are generally low.

The foregoing conclusion must not be interpreted as being applicable to all types of air-borne organisms. Possibly it applies only to organisms whose natural environment is one of high humidity or the equivalent. For such organisms it is reasonable to expect that air of low humidity is a less favorable environment which may result in a decreased resistivity of such organisms. If this is true, the reverse effect of humidity would be expected for micro-organisms whose natural environment was not water or very humid air. Some experimental data obtained with air from a poultry house indicate that the organisms collected there, largely

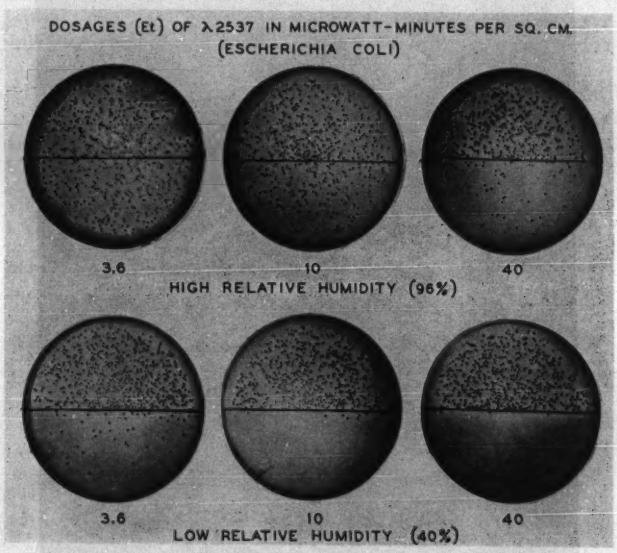


FIG. 4. Illustrating the effect of humidity on the resistivity of air-borne *E. coli* for dosages *Et* of 3.6, 10 and 40 microwatt-minutes per sq. cm.

associated with dust, are less resistant in air of high humidity than in that of low humidity. There are many aspects of this problem which will be dealt with in a later paper. For the present purpose it suffices to state that the air-borne micro-organisms of chief interest in occupied interiors appear to be decidedly easier to kill with germicidal radiant energy in air of relatively low than high humidities. We also have some evidence that *E. coli* gathered in humid air appeared to have a higher resistivity than those caught in dry air when irradiated on a nutrient surface.

Fig. 5 illustrates several points of interest. The variety of air-borne organisms obtained from a poultry house was subjected to dosages *Et* of 40, 80, 160 and 320 microwatt-minutes per sq. cm., while floating in the air of a tunnel (Fig. 9) of small uniform cross-section. The first two rows are typical results with these air-borne organisms. In the third vertical row are shown the results of irradiating these organisms

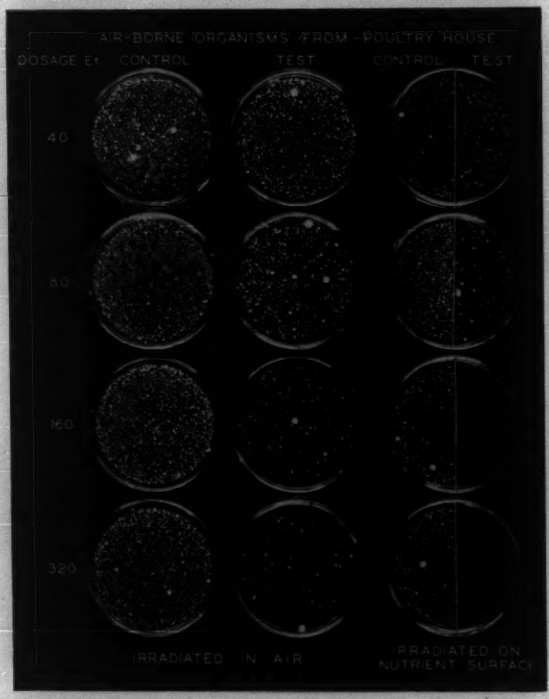


FIG. 5. Illustrating the killing of a variety of air-borne micro-organisms, obtained from a poultry house, by various dosages *Et* of energy of λ2537. When irradiated in air, they were more resistant than when irradiated on the surface of a nutrient.

after being caught on the surface of the nutrient. Various samplings were used, and one-half of the nutrient area was subjected to the dosages indicated. It is seen that this variety of organisms obtained from the air of a poultry house was generally less resistant to germicidal energy when exposed on the nutrient surface than when irradiated in air.

MICRO-ORGANISMS EXPELLED FROM RESPIRATORY ORGANS.

Tests of saliva from various adults revealed concentrations of micro-organisms aggregating 10 to 30 million per cubic centimeter. When a person breathes normally, few micro-organisms are expelled from the respiratory organs. However, many of these are expelled by individuals when talking, singing, coughing or sneezing. These are not newly discovered facts, but they need emphasizing, and interest in them is greatly augumented by the new practical possibilities of disinfecting air for the protection of occupants of interiors. It is somewhat surprising that so little attention has been given to making air safe to breathe compared with the interest, for example, in making milk and water safe to drink. Considering that we are forced to breathe the air wherever we are, but can generally choose the water or milk we drink, knowledge of, and interest in, many aspects of air-borne organisms are relatively scanty. Perhaps some lack of data and interest in air-borne organisms has been due to inefficient and time-consuming methods of air-sampling.[1]

It is now known that organisms expelled from the nose and throat

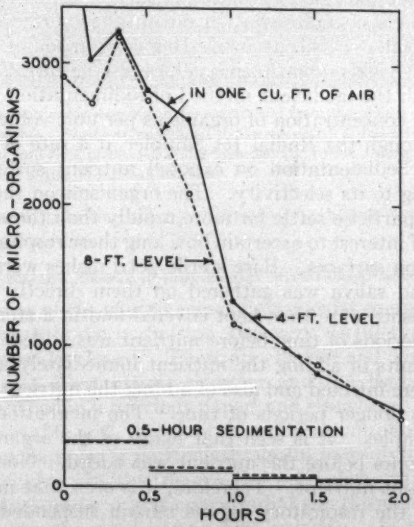


FIG. 6. Showing the rate of reduction of the number of air-borne respiratory micro-organisms per cubic foot of air in a room after a long period of spraying them into the air. Quantitative samplings were made simultaneously in the center of the room at two levels with the Duplex Radial Jet Sampler, each unit sampling one cubic foot of air per minute. This sampler is far more effective than sedimentation on a nutrient for half-hour periods.

remain suspended in the air for some time. Doubtless some die naturally, and some settle more rapidly on the larger droplets and dust particles. The rate of disappearance from the air is illustrated in Fig. 6. Saliva was "nebulized" into the air of a closed room for two hours by means of a DeVilbiss No. 40 nebulizer which produced a very fine spray 5 feet above the floor on the side where the steam radiators were located. The radiators were merely warm, and moderate convection currents supplied the only movement of air. Immediately upon shutting off the nebulizer, air-samplings were made simultaneously with our Duplex Radial Jet Bacterial Air-Sampler in the center of the room, at 4 feet and 8 feet above the floor. This sampler is highly efficient and catches the air-borne organisms directly on the nutrient in petri dishes. Appropriate incubation revealed more than 3000 organisms per cu. ft. of air immediately after spraying ceased. The rate of disappearance shown in Fig. 6 is not rapid. After one hour, the concentration of air-borne organisms was still about 34 per cent. of the initial concentration. After a lapse of 2 hours, the relative concentration was 14 per cent. of the initial value.

In the lower part of Fig. 6, the results of samplings obtained by half-hour periods of sedimentation on nutrient surfaces in open petri dishes are shown. This is an interesting comparison of an efficient air-sampler which yields quantitative values of concentration of air-borne organisms with the inefficient method of sedimentation which does not determine the concentration of organisms per unit volume of air. The air passed through the Radial Jet Sampler at a rate of one cubic foot per minute. Sedimentation on exposed nutrient surfaces is open to criticism owing to its selectivity. The organisms on the heavier droplets and dust particles settle far more rapidly than those less weighted.

It is also of interest to ascertain how long these respiratory organisms live in air or on surfaces. Bare sterile petri dishes were placed before the mouth and saliva was gathered on them directly by sputtering. These petri dishes were then kept covered and in a sterile atmosphere for different periods of time before nutrient was added. In Fig. 7 are shown the results of adding the nutrient immediately after the sterile bare dishes were infected and also of adding the nutrient after the lapse of successively longer periods of time. The incubation was identical for all the samples. It is seen that many of the organisms remained alive for 36 hours before the nutrient was added. None survived for 48 hours without nutrient. Therefore, it is seen that micro-organisms expelled from the respiratory organs remain suspended in the air for some time and live for a long time without an artificial supply of nutrient. For these and other practical reasons, it was decided to study the micro-organisms expelled from the respiratory organs. The results supplement those of previous investigations[2] with *E. coli*. Furthermore, a major practical objective of disinfection of air to protect occupants

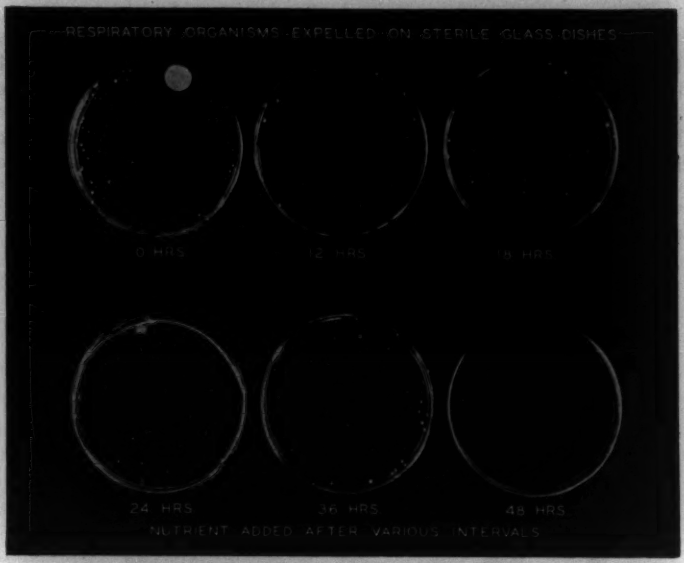


FIG. 7. Respiratory micro-organisms were sputtered from the mouth on a series of sterile barren glass petri dishes. Nutrient was added to the respective dishes after lapses of 0, 12, 18, 24, 36 and 48 hours and then incubated under identical conditions. Many of these organisms survived for 36 hours without artificial nutrient.

from cross-infection is the killing of micro-organisms expelled from the respiratory organs.

### KILLING AIR-BORNE RESPIRATORY MICRO-ORGANISMS.

In our studies of the effectiveness of germicidal energy in destroying or inactivating air-borne organisms, two very useful types of bacterial air-samplers were developed. These are efficient and convenient to use. Both the Duplex Electrostatic Sampler and the Radial Jet Sampler have been described in a previous paper[6] and elsewhere.[1] The former is particularly portable and, therefore, is useful in sampling air anywhere. The Radial Jet Sampler is particularly useful in studying effects which take place quickly. In this device the petri dish, with the nutrient exposed, revolves under a stationary radial slit through which a jet of air impinges upon the nutrient at a high velocity. In this sampler the petri dish is revolved by a Telechron motor one revolution in 0.5, 1, 2 or 3 minutes.

Bourdillon has used this method to obtain a chronological record of the effect of a germicide on air-borne organisms. In correspondence

with the authors, he has been generous of his time and experience. Our Radial Jet Sampler is essentially the same in principle as that described by Bourdillon, Lidwell and Thomas,[7] but was developed independently of their work. In addition, we have developed a Radial Jet Sampler containing two sampler units as illustrated in Fig. 8. The radial slit is seen on the under side of the lid of one of the units. This device makes it possible to make two samplings simultaneously at the same rate of

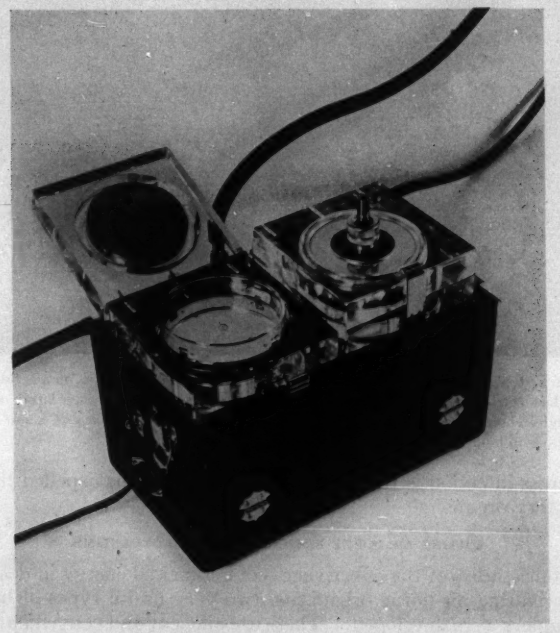

FIG. 8. The Duplex Radial Jet Air-Sampler, consisting of two identical sampling units, each similar to the one previously described.[1,6]

air-flow. For example, infected air may be drawn simultaneously through two similar tunnels at the same rate as illustrated in Fig. 9. The infected air in one tunnel, *A*, may be exposed to a given intensity *E* of germicidal energy through the cover of clear quartz. The other tunnel, *B*, is identical in cross-section, but has an opaque cover. The device is carefully adjusted so that air passes through both tunnels at the same rate and into the two units, respectively, of the Duplex Radial Jet Sampler.

The germicidal energy is obtained from four 8-watt germicidal sources which can be raised or lowered for varying the intensity. This is also achieved by varying the rate of air-flow or by varying the length of the quartz window of tunnel *A* by the use of opaque covers. In laboratory work, the respiratory organisms may be expelled directly into a funnel connected to the inlet of the apparatus illustrated in Fig. 9. In another method, these and other micro-organisms are atomized or nebulized into an "infection chamber" with a volume of about 30 cu. ft. of air.[6] This infected air is drawn into the common inlet of the two tunnels for studying the effects of various dosages *Et* of germicidal energy.

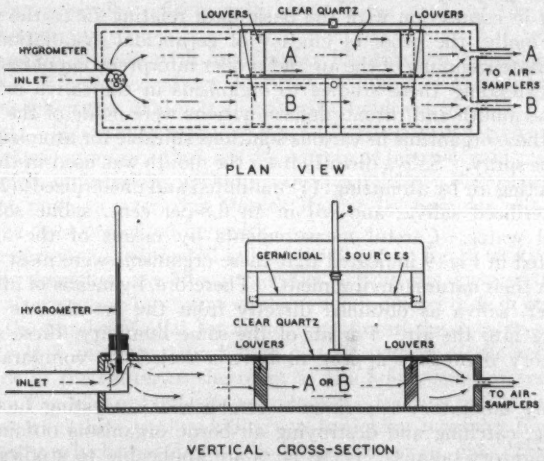


FIG. 9. Apparatus consisting of two separate tunnels, *A* and *B*, through which infected air passes at the same rates to the air-samplers. While the air passes through *A*, it is exposed to measured dosages *Et* of germicidal energy through the plate of clear quartz.

A third method is to nebulize the saliva into a room for long periods and note the effects of one or more germicidal lamps in irradiating the air above a 7-foot level. Samples of air are taken simultaneously at 4-foot and 8-foot levels. The former represents the level at which occupants breathe air which receives only low intensities of germicidal energy reflected from the upper regions. Air at the 8-foot level receives germicidal energy directly from the unit or units provided for the purpose. In a sense, the region above the 7-foot level is primarily the irradiation chamber. Ordinary convection currents dilute the air of the lower region with disinfected air from the upper region. This is a

very important factor in this method of disinfecting the air in occupied rooms.

In earlier work, the authors and their colleagues made systematic studies of the killing of *E. coli* in air flowing at different rates in a tunnel specially built for the purpose.[1,2] Extensive data were obtained in such a manner that by means of mathematical treatment they could be applied to the practice of disinfecting air in ducts or in occupied rooms. In fact, practices which appear to be successful were founded upon those data obtained with *E. coli*. However, it is desirable to extend the data to other air-borne organisms. Adequate data are available pertaining to the intensities of germicidal energy $E$ obtainable by suitable fixtures installed properly in occupied rooms and elsewhere. These are of interest in connection with the basic data relating $Et$ to the per cent. kill. Finally, the proof of efficacy of germicidal installations lies in appropriate sampling of the air and proper interpretation of results.

In extending these studies to organisms in the saliva or expelled from the mouth and throat, determinations were made of the resistivities of these organisms in various solutions suitable for atomizing into a very fine spray. Saliva directly from the mouth was used in three ways for infecting air by atomizing: (1) undiluted and unsterilized; (2) diluted with sterilized saliva; and (3) in an 0.8-per cent. saline solution in distilled water. Careful measurements by means of the apparatus illustrated in Fig. 9 indicated that these organisms were most resistant when in their natural environment. Therefore, by means of an efficient nebulizer, saliva as obtained directly from the mouth was used for spraying into the air. For air of the same humidity, these air-borne respiratory organisms appear to have a resistivity comparable with *E. coli*.

Many laboratory experiments established interesting facts about spraying, catching and destroying air-borne organisms obtained from the respiratory organs. These facts are applicable to studies and installations of germicidal lamps in air-ducts and unoccupied rooms. However, the disinfection of air in occupied rooms involves other problems and is of more extensive practical interest. Therefore, the present discussion deals with results obtained in ordinary rooms.

The results illustrated in Fig. 6 were obtained in a room 17 ft. by 17 ft. with an 11-ft. ceiling. Steam radiators were on one side of the room and above them, at a level of 5 feet above the floor, the organisms in saliva were nebulized into a very fine spray. After 40 minutes, the spraying ceased and the air was sampled as already explained. It is seen that the concentration of air-borne respiratory organisms remained high for fully an hour. Incidentally, the spray introduced about one million of these organisms into the air each minute.

In this same room a 30-watt germicidal lamp in an efficient reflector was installed in the center of the wall opposite the radiators and nebu-

lizer. It was so designed that only the air above the 7-foot level was directly irradiated with germicidal energy. Owing to the fact that it takes time for the germicidal lamp to reach its maximum output of germicidal energy, it was kept turned on and covered with an opaque cloth. This could be removed to irradiate the upper stratum of air or replaced to cease irradiating the air. Air was sampled in the center of the room simultaneously at the 8-foot and 4-foot levels. The air at the former level was directly irradiated when the germicidal unit was uncovered. The 4-foot level represents that of the occupants of a room, and this air, including all the air below the 7-foot level, receives only the relatively slight amounts of germicidal energy reflected from the upper walls and ceiling which were coated with ordinary oil paint. Such paint generally reflects only about 5 per cent. of the incident germicidal energy.

In samplings made with our Duplex Electrostatic Sampler, it was found that it collected about 30 times as many of these respiratory organisms when the 7000-volt electrostatic field was operating as when it was not. This reveals a much higher effectiveness of the electrostatic field for these organisms than for the variety of micro-organisms usually encountered in interiors, including dust particles. For reasons that should be obvious later, our Duplex Radial Jet Sampler was used to obtain the data presented herewith.

After spraying the infected saliva into the room for 15 to 30 minutes, as already described, the 30-watt germicidal unit was uncovered. Continuous air-sampling by means of the revolving petri dish in one of the units of the Duplex Radial Jet Sampler produced the data presented in Fig. 10. It is seen that the killing or inactivation of the respiratory organisms in the center of the room at the 8-foot level proceeds very rapidly. The kill is practically complete in a fraction of a minute. At the 4-foot level there is some killing due to the low intensity $E$ of germicidal energy, which was about 0.35 microwatt per sq. cm. *It should be noted that the spraying of respiratory organisms continued throughout the period of irradiation as it did for the period preceding this.*

It is seen in Fig. 10 that at the end of 4 minutes the concentration of these air-borne organisms at the occupancy level (4 feet) was reduced to about 25 per cent. of the initial value. At the end of 8 minutes it was reduced to about 5 per cent. and was still diminishing. With the germicidal unit and the spray in continuous operation, it is seen that the concentration of these air-borne respiratory organisms would be reduced and maintained at a very low value at the occupancy level.

The reduction in concentration at the occupancy level is due to two factors. Experimental evidence reveals that the low intensities of germicidal energy in the stratum of air below the 7-foot level are effective in killing these organisms. However, the reduction in concentration of the air-borne organisms in this region is also due to dilution by dis-

infected air from the stratum above the 7-foot level. Moderate convection currents rose from the steam radiators to produce circulation which produced dilution of the lower air by disinfected air from the upper or "irradiation" stratum. Circulation of air is very important

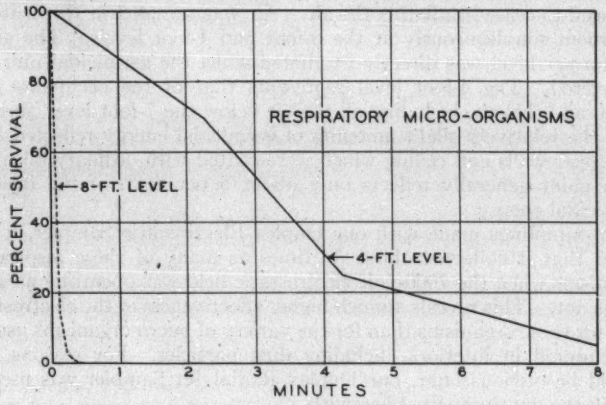


FIG. 10. Respiratory organisms in saliva were nebulized continuously into the air of a room 17 ft. by 17 ft. with an 11-foot ceiling. Air-samplings in the center of the room were begun before beginning to irradiate the air above the 7-foot level with a 30-watt germicidal lamp. The concentration of organisms at the 8-foot level decreased to zero in less than a minute.

for this reason and was studied and stressed in our earlier papers.[1] Many actual samplings in classrooms in which germicidal units are installed verified the effect of circulation.

In Fig. 11 are presented the results with a typical series of petri dishes exposed in the Duplex Radial Jet Sampler simultaneously at the 4-foot and 8-foot levels. These reveal the progress in relation to elapsed time. After spraying the saliva in the room for 30 minutes as described, the first two petri dishes reveal the relative concentration before the 30-watt germicidal unit was uncovered at 2:03. These petri dishes revolved at a uniform rate once in 3 minutes. The next two petri dishes show the rapid rate of decrease in concentration at the two levels, respectively, immediately after beginning irradiation of the air above the 7-foot level. Each sector in these cases represents 0.5 minute. It is seen that before one minute elapsed practically a complete kill was achieved at the 8-foot level. The pair of petri dishes exposed for the period of time, 2:06 to 2:09, reveals a practically complete kill. At 2:09 the germicidal unit was turned off and it is seen that the concentration of these air-borne respiratory organisms had risen

again to the initial value in 15 minutes. The spraying continued through the period from 2:00 to 2:27 as it did for 30 minutes preceding irradiation. The data represented in Fig. 10 are the averages of three series, of which Fig. 11 is a specific one.

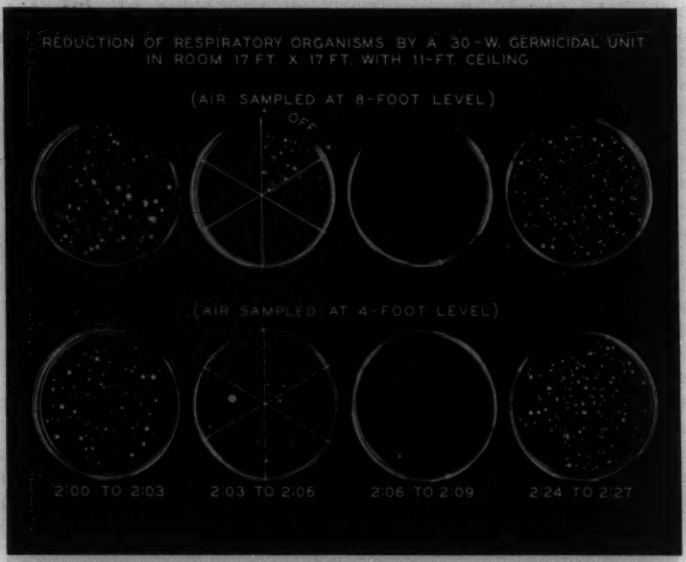
REDUCTION OF RESPIRATORY ORGANISMS BY A 30-W. GERMICIDAL UNIT
IN ROOM 17 FT. X 17 FT. WITH 11-FT. CEILING
(AIR SAMPLED AT 8-FOOT LEVEL)
OFF
(AIR SAMPLED AT 4-FOOT LEVEL)
2:00 TO 2:03
2:03 TO 2:06
2:06 TO 2:09
2:24 TO 2:27

FIG. 11. Showing the reduction of respiratory organisms by one 30-watt germicidal lamp which irradiated the air of a room above the 7-foot level. The organisms were nebulized into the room continuously, beginning 30 minutes before irradiation began at 2:03. All petri dishes were exposed in the Duplex Radial Jet Sampler to the same amount of air.

Fig. 12 is of interest in revealing the progress of killing of these air-borne organisms during a short period of irradiation. The left-hand illustration is that of a petri dish exposed in one of the units of the Duplex Radial Jet Sampler at the 8-foot level. This petri dish revolved uniformly once in one minute. The germicidal unit was not uncovered until the petri dish had revolved a quarter of its entire revolution. Then at zero second it was uncovered. It is seen that the kill takes place rapidly. In this case the per cent. surviving was already very low at the end of 15 seconds of irradiation. It is emphasized that this record was made at the center of the room, at the 8-foot level, under the conditions already described, with one 30-watt germicidal unit located in the center of one side of the 17 ft. by 17 ft. room at the 7-foot level.

The warm radiators were on the opposite side of the room and the nebulizer was above them at the 5-foot level.

The speed at which these air-borne organisms were killed or inactivated at the 8-foot level is very striking. The right-hand illustration in Fig. 12 is typical of the results at the 4-foot level in the center of the room. In this case the petri dish exposed in one of the units of the Duplex Radial Jet Sampler rotated 30 seconds before the germicidal unit was uncovered. The rotation was started and stopped to obtain

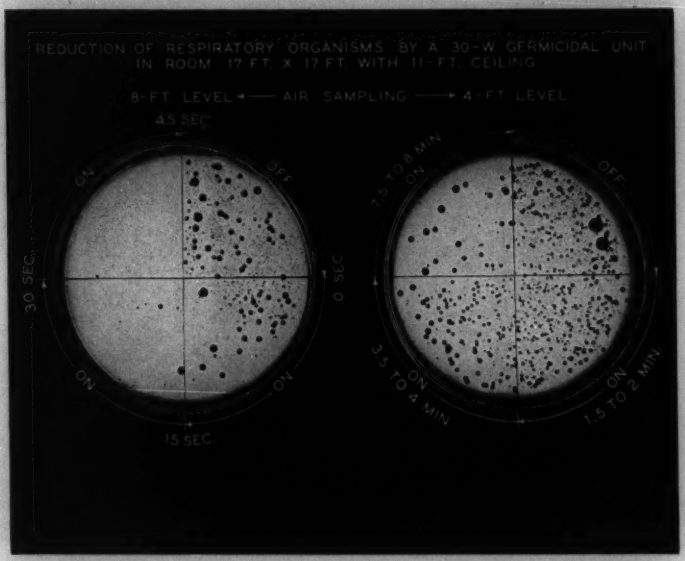


FIG. 12. Examples of petri dishes revolved in the Duplex Radial Jet Sampler. Petri dishes such as the one on the left provide quantatitive measurements during the rapid rate of killing at the 8-foot level. The right-hand illustration reveals the survival at various time-intervals indicated.

samplings at various intervals. It is seen that for the period 7.5 to 8 minutes after the germicidal unit was uncovered, the concentration of these air-borne respiratory organisms was greatly reduced as also shown in Fig. 10.

The intensities of germicidal energy in the center of the room, where the samplings were made simultaneously at the 4-foot and 8-foot levels, were 0.5 and 32 microwatts per sq. cm. Each value above is the sum of the maximum intensity as measured on a vertical plane facing the

germicidal fixture and on a horizontal plane facing the ceiling. It is particularly interesting to note that the intensity of 0.5 microwatt sq. cm. was effective in killing these organisms. The reduction at the 4-foot level is partly due to dilution by disinfected air from the upper stratum. However, the moderate convection currents cannot possibly account for most of the decrease in concentration of the organisms at the 4-foot level. This was proved by various experiments.

At this point it appears of interest to include typical data obtained in a classroom of a public school. The room was 23 ft. by 33 ft. with a 12-foot ceiling. Four 30-watt germicidal lamps in proper fixtures were located 7 feet above the floor. The air was sampled in the center of the room at 4-foot and 8-foot levels. The germicidal lamps had been operated for several months. Before cleaning them and the reflectors, the intensities at the two locations where air-sampling was done were 0.35 and 9.6 microwatts per sq. cm. After cleaning, these values rose to 0.61 and 14.1, respectively. Incidentally, when new germicidal lamps were installed in clean reflectors, these values rose to 0.75 and 18.2, respectively. These intensities are the sum of those measured on a vertical plane facing each wall, respectively, and also on a horizontal plane facing the ceiling.

Measuring the intensity of germicidal energy to which an air-borne micro-organism is subjected is a problem of much practical interest. There is good reason for integrating the intensity $E$ in all directions at a given point. An approximation can be reached by adding measurements made in various directions. However, we are working on integrating methods essentially similar to a spherical receiver. Until such an integrator is available, we use the sum of the intensities obtained in a vertical receiver facing the ceiling and each of the four walls or germicidal units.

The results obtained in the classroom before the lamps and reflectors were cleaned are shown in the left-hand portion of Fig. 13. The respiratory micro-organisms were sprayed in the room as already described. This spraying continued for six hours beginning in the morning. The germicidal units were covered with opaque cloth. After about 30 minutes of spraying, air-sampling was begun simultaneously in the center of the room at the two levels. During the morning the steam radiators were moderately warm and, therefore, they produced moderate convection currents which resulted in some forced circulation of air between the upper stratum of air which was directly irradiated and the lower stratum of air which was subjected to low intensities of germicidal energy. At noon the radiators were turned off and samplings were made after they became cold.

The two sets of data are separated in Fig. 13. It is seen that the concentration of these air-borne respiratory organisms was about the same initially at the 4-foot and 8-foot levels before the germicidal units

were uncovered. Then the concentration at the 8-foot level quickly decreased to a very low value. At the 4-foot level the concentration reached a fairly low value in 4 minutes after the germicidal units were uncovered late in the morning when the radiators were warm. The concentration did not decrease as much after the germicidal units were uncovered late in the afternoon. In each case the zero on the time-scale indicates the exact time when the germicidal units were uncovered. During these tests no one occupied the room excepting one person who

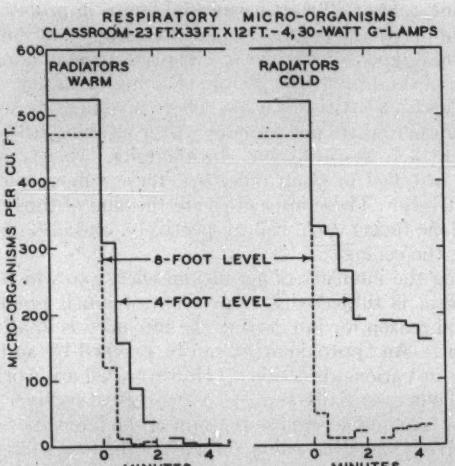


FIG. 13. Showing the results of a standard germicidal installation in killing respiratory organisms in a classroom. Four 30-watt germicidal units were installed on the walls so as to irradiate the air above the 7-foot level. The concentration of organisms decreases rapidly at the 8-foot level. At the 4-foot level the effect of reduced convection currents (radiators cold) is evident. Saliva was nebulized continuously into the vacant schoolroom throughout the period of the test.

was actually sampling the air. Thus little dust was stirred up and the air-borne organisms were almost entirely those in the nebulized saliva.

Although such data as illustrated in Fig. 13 support other conclusions presented in this paper, they particularly provide an opportunity to emphasize the importance of circulating the air in a room where the upper stratum is used as an irradiation chamber. We have obtained much evidence in basic researches and in sampling air in various classrooms having germicidal installations. The effect of circulating air by convection currents, by fans and other means is very evident. Al-

though this paper adds very definite evidence that the low intensities of germicidal energy, which are permissible at the levels of the occupants, are decidedly effective in killing air-borne organisms, some circulation is desirable. Apparently convection currents rising from warm radiators are sufficient in rooms of the size of classrooms. Of course, convection currents rise from the occupants themselves and air cooled by windows in cold weather falls. Ventilating systems also stir up the air. All these factors contribute to make it practicable to irradiate directly the upper stratum of air in occupied rooms. However, adequate interchange of air between the upper and lower strata is desirable.

In hospital installations, a tentative maximum allowable value of 0.5 microwatt per sq. cm. at bed level has been proposed for adequate

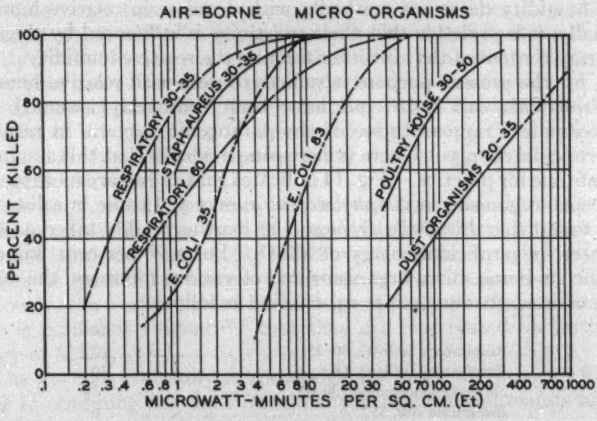


FIG. 14. The resistivities of various air-borne organisms are shown by the dosages *Et* required to kill or inactivate any given percentage of the organisms.

eye protection over an 8-hour period. From the table above and Fig. 14, it is seen that this intensity is sufficient to kill 90 per cent. of the respiratory organisms in 4 minutes at a humidity of 30 to 35 per cent., a reasonable humidity indoors in the winter.

### RESISTIVITIES OF AIR-BORNE MICRO-ORGANISMS.

In the disinfection of air by means of germicidal lamps, the determination of the resistivities of air-borne micro-organisms is very important. In general, the resistivities of the bacteria group, and particularly of those organisms pathogenic to human beings or intimately associated with them are less than the resistivities of molds and yeasts.

Inasmuch as this paper deals primarily with the disinfection of air for the protection of occupants from cross-infection, this present discussion is only briefly extended beyond those organisms which appear to be representative of pathogenic bacteria.

In Fig. 14 are plotted some of the results obtained for some air-borne organisms of human origin. The variety of organisms from the air of a poultry house and those associated with air-borne dust particles in ordinary interiors are included for comparison. The socalled respiratory organisms were introduced into the air by nebulizing saliva. They represent a mixture of many different types. The numbers on the curves in Fig. 14 indicate the relative humidity of the air at the time of sampling and testing. There appears to be little question that the resistivity of organisms whose natural habitat is the equivalent of very high humidity decreases markedly with decrease in relative humidity. Actually, it is probable that their resistivity is influenced by the actual moisture content of the air rather than by the relative humidity. However, for the present purpose it suffices to deal with relative humidity.

*Escherichia coli* or *B. coli* have been commonly assumed to be approximately representative of the pathogenic bacteria in resistivity to germicidal energy. There is increasing evidence that this assumption is a safe one for practice. Fig. 14 indicates that *E. coli* are more resistant than such organisms as *Staphylococcus aureus* and those in saliva. We have found that *Eberthella typhosa* is at least as readily killed as *E. coli* in water by germicidal energy of λ2537. For a 90-per cent. kill of the specific air-borne micro-organisms and of various mixtures, the dosages *Et* in microwatt-minutes per sq. cm. are as follows:

| | *Et* |
|---|---|
| Respiratory (saliva), 30–35 | 2 |
| Respiratory (saliva), 60 | 10 |
| *Staphylococcus aureus*, 30–35 | 3½ |
| *Escherichia coli*, 35 | 6 |
| *Escherichia coli*, 83 | 30 |
| Poultry house, 30–50 | 180 |
| Dust in ordinary room, 35 | 1000 |

The approximate relative humidity in per cent. is indicated in each case.

It is of interest to return to Fig. 14 and note the degree of kill of the organisms and mixtures of them by dosages *Et* of 1, 10, 100, and 1000 microwatt-minutes per sq. cm. It is obvious from such a survey that a complete kill of the mixture of organisms in saliva, for example, is achieved at dosages which have relatively little effect on the mixture of dust organisms. The same is true of *E. coli*.

The most important practical import of this lies in interpreting the results of air-samplings in occupied interiors in which germicidal lamps have been installed for the purpose of reducing the possibility of cross-infection by air-borne micro-organisms. For example, suppose air-

samplings with a satisfactory device and nutrient, followed by suitable incubation, reveal only an overall 50-per cent. reduction in the concentration of air-borne organisms. This does not mean that 50 per cent. of the pathogenic bacteria remain in the air breathed by the occupants. There will generally be dust-borne organisms in the air of occupied rooms. From the evidence presented in Fig. 14 and in preceding sections, this apparent 50-per cent. overall reduction very likely means nearly 100- per cent. reduction of the air-borne organisms that the germicidal installation is designed to kill.

The foregoing statement applies only to the protection of occupants by means of installations of germicidal lamps. Where the prevention of contamination of food and other products is involved, much higher dosages are generally necessary. However, these are readily obtainable in various ways with adequate protection of the worker. In the protection of occupants of a room in which the upper stratum of air is directly irradiated, there is a practical limit to the amount of germicidal energy that can be permitted to be reflected from the ceiling and upper walls to the occupants in the lower stratum of air. However, the results presented in this paper add further evidence of the practicability of this method in greatly reducing the possibility of cross-infection by air-borne pathogenic micro-organisms.

It is emphasized that many respiratory organisms introduced into the air in saliva may live up to 36 hours without artificial nutrient. On the other hand, they are readily killed or inactivated by relatively small dosages of germicidal energy which are easily obtained in practice. Obviously, the work reported in this paper does not include viruses, but there is published evidence[8,9] that they are inactivated by germicidal energy of $\lambda 2537$.

The authors gratefully acknowledge the work of Elton T. Leppelmeier in obtaining the data from many exposures and counts of petri dishes.

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# EROSION IN VENT PLUGS, THE EFFECT OF VENT DIAMETER.

BY

JAMES H. WIEGAND, Ph.D.[1]

## PART I.

ABSTRACT.

Erosion in vent plugs is studied in a 37 mm. Gun which has been cut off at the end of the chamber. Plugs with vent diameters from 0.04 to 0.63 inches and vent lengths from one to four inches are held in the position normally occupied by the projectile. The weight losses due to erosion are in fair agreement with values calculated from heat transfer theory, assuming melting of the surface, for charges of propellant powder above a minimum value. The weight loss due to melting increases as the weight of charge, the web thickness, the length of the vent, and the gas temperature are increased, and decreases as the vent diameter and the melting point of the metal are increased. The minimum charge to produce melting increases rapidly with increases in vent diameter, but the maximum pressure corresponding to this charge increases only slightly. For charges below this minimum, the erosion is shown to be of a chemical nature by the significant decrease due to the elimination of sulphur from the black powder primer.

The erosion of vent plugs by powder gases has been used for many years as a means of studying erosion on a laboratory scale for application to the study of erosion of guns. Such a method offers a wide range of variables of pressure-time relations, weight of charge, size and shape of vent plug, and vent metal. The use of such an apparatus for studying factors affecting gun erosion requires the selection of the proper range of variables and the proof that the relationship to gun erosion is a direct one. Most work done in the past has involved small vents with long discharge times, usually operated at maximum pressures comparable to those in guns. This paper covers vent erosion tests over a wide range of the variables of vent diameter, with resulting variation in the pressure-time relationship.

### PREVIOUS WORK.

The literature on erosion is quite extensive, but only a portion is useful. Many articles have been written about erosion and elaborate theories have been developed, particularly about erosion in guns, but there is little reliable experimental data available. The work of Noble (6) is one of the earliest experimental sources. His chief contribution was to show that erosion in a vent was a function of the flame temperature of the powder gases. Vieille (11) did a series of important experi-

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ments with closed bombs of capacities of 17.8, 75 and 340 cc. equipped with vent plugs and established the effect of flame temperature. He also found the relative erodability of metals and showed that the melting point of the metal is important. He observed a peculiar periodic effect of the erosion on the walls of the vent, which evidences itself as a series of rings when the vent is viewed from the end.

The most comprehensive work on the subject is that of Greaves, Abram and Rees (3). They made a careful study of all previous work and made a large number of experiments of their own. They concluded that erosion was due to melting of the surface of the vent. They also showed that this melting starts at a definite pressure, inde-

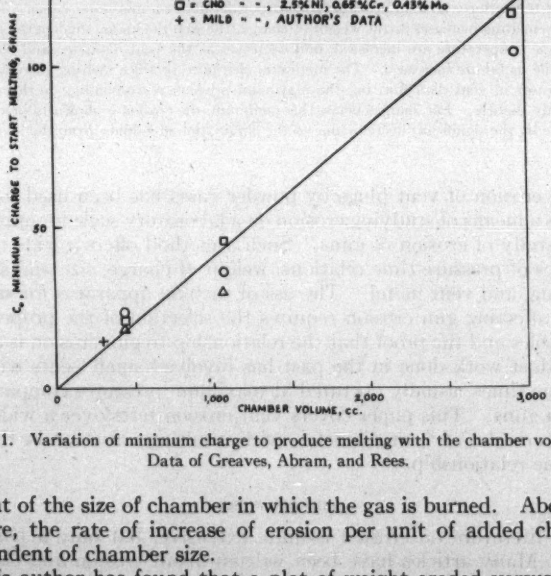



FIG. 1. Variation of minimum charge to produce melting with the chamber volume. Data of Greaves, Abram, and Rees.

pendent of the size of chamber in which the gas is burned. Above this pressure, the rate of increase of erosion per unit of added charge is independent of chamber size.

This author has found that a plot of weight eroded versus weight of charge gives much better correlations than the plot of weight eroded versus pressure used by Greaves, Abram and Rees. This might be expected as weight of charge is the independent variable and can be determined most accurately. All of the data of these authors which allowed it, have been analyzed by computing the regression line, or least square straight line, through their data. The results are given in

TABLE IA.

*Summary of Recalculation of Data of Greaves, Abram and Rees.*

Erosion Expressed in Terms of $W/(C-C_0)$, and Values of $C_0$ Expressed as $C_0/V_0$, the Minimum Loading Density to Produce Melting. The vent diameter was 2 mm.

| Mark | % C | % Si | % Mn | % S | % P | % Ni | % Cr | % Other Element | Condition | Brinell | Yield Point, Tons/in.² | Max. Load, Tons/in.² | Cordite Lot A $V_0=1080$ cc. | | Cordite Lot B $V_0=1080$ cc. | | Cordite Lot B $V_0=440$ cc. | | Cordite Lot B $V_0=2940$ cc. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | $\frac{W}{C-C_0}$ | $\frac{C_0}{V_0}$, g./cc. | $\frac{W}{C-C_0}$ | $\frac{C_0}{V_0}$, g./cc. | $\frac{W}{C-C_0}$ | $\frac{C_0}{V_0}$, g./cc. | $\frac{W}{C-C_0}$ | $\frac{C_0}{V_0}$, g./cc. |
| ECP | 0.03 | 0.01 | 0.02 | 0.002 | 0.013 | — | — | — | Rolled | 109 | 12 | 21 | | | 0.0330 | 0.0435 | | | | |
| CMS | 16 | 05 | 51 | 0.076 | 70 | — | — | — | Rolled | 111 | 13 | 26 | 0.0393 | 0.0339 | | | 0.0384 | 0.0542 | 0.0301 | 0.0356 |
| AYM | 42 | 13 | 80 | 36 | 37 | — | — | — | Oil hardened and tempered | 179 | 24 | 40 | 384 | 270 | 389 | 440 | | | | |
| CDN | 39 | 11 | 1.12 | 35 | 25 | — | — | — | " | 183 | 25 | 39 | | | 403 | 452 | | | | |
| CDO | 36 | 09 | 2.24 | 27 | 25 | — | — | — | " | 239 | 40 | 50 | | | 373 | 402 | | | | |
| DRD | 30 | 09 | 0.17 | 45 | 27 | — | — | W 1.72 | " | 179 | 27 | 37 | | | 392 | 434 | | | | |
| CFW | 32 | 13 | 66 | 26 | 23 | 3.63 | 0.05 | — | " | 198 | 30 | 43 | 400 | 271 | 362 | 408 | | | | |
| | | | | | | | | | | | | | | | 418 | 444 | | | | |
| CFX | 29 | 12 | 56 | 23 | 30 | 3.67 | 0.62 | — | " | 234 | 37 | 49 | 391 | 283 | 391 | 500 | 389 | 235 | 386 | 462 |
| GVR | 25 | 26 | 45 | 15 | 10 | 3.39 | 0.75 | — | " | 230 | 38 | 48 | | | 413 | 393 | | | | |
| CNO | 28 | 15 | 48 | 32 | 28 | 2.45 | 0.65 | Mo 0.43 | " | 259 | 47 | 56 | | | 361 | 420 | 409 | 488 | 308 | 397 |
| GME | 28 | 23 | 37 | 32 | 24 | 3.36 | 0.90 | V 0.25 | " | 245 | 43 | 51 | | | 360 | 306 | | | | |
| DOO | 36 | 12 | 21 | 37 | 22 | — | 1.2 | V 0.38 | " | 306 | 54 | 64 | | | 327 | 361 | | | | |
| AYR | 43 | 13 | 20 | 80 | 24 | 0.20 | 12.37 | — | " | 255 | 42 | 54 | 640 | 247 | 617 | 242 | | | | |
| FXL | 13 | 15 | 21 | 45 | 40 | 0.20 | 12.40 | — | Rolled | 202 | 30 | 41 | | | 597 | 310 | | | | |
| FTQ | 23 | 11 | 15 | 34 | 35 | 2.04 | 17.9 | — | " | 296 | 47 | 62 | | | 720 | 218 | | | | |
| FKE | 15 | 16 | 11 | <0.005 | 18 | 7.8 | 19.8 | — | " | 171 | 13 | 54 | | | 802 | 250 | | | | |
| FOH | 37 | 11 | 1.30 | 0.02 | 0.03 | 35.6 | 11.0 | — | " | 216 | 17 | 42 | | | 707 | 194 | | | | |
| FNO | 02 | 13 | 0.30 | <0.01 | 0.01 | 34.7 | 0.26 | — | " | 175 | 35 | 39 | | | 551 | 347 | | | | |
| FNP | 11 | 11 | 37 | 0.025 | 0.013 | 36.7 | 0.005 | — | " | 217 | 36 | 46 | | | 572 | 383 | | | | |
| CXL | | | 1.0 | | | 70.0 | | Cu 28.0 | | | | | | | | | | | | |
| | | | | | | | | Fe 1.0 | | | | | 826 | 303 | | | | | | |
| FHT | | | | | | 100 | | | | | | | | | 546 | 482 | | | | |

TABLE IB.

*Summary of Recalculation of Data of Greaves, Abram and Rees.*

Erosion Expressed in Terms of $W/(C-C_0)$, and of $C_0$, grams, the Minimum Charge to Produce Melting.
The vent diameter was 2 mm.; chamber volume 1080 cc. for the following data.

| Mark | Cordite Lot B $T_0=3170°$ K. | | Charge A $T_0=3120°$ K. | | Charge B $T_0=3020°$ K. | | Charge C $T_0=2970°$ K. | | Charge D $T_0=2870°$ K. | | Charge NCT $T_0=2770°$ K. | | Charge E $T_0=2570°$ K. | | Charge F $T_0=2370°$ K. | | Charge G $T_0=2320°$ K. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\frac{W}{C-C_0}$ | $C_0$ | $\frac{W}{C-C_0}$ | $C_0$ | $\frac{W}{C-C_0}$ | $C_0$ | $\frac{W}{C-C_0}$ | $C_0$ | $\frac{W}{C-C_0}$ | $C_0$ | $\frac{W}{C-C_0}$ | $C_0$ | $\frac{W}{C-C_0}$ | $C_0$ | $\frac{W}{C-C_0}$ | $C_0$ | $\frac{W}{C-C_0}$ | $C_0$ |
| CFX | 0.0391 | 54.0 | | | 0.0299 | 37.2 | | | | | 0.0223 | 61.2 | 0.0167 | 67.8 | | | | |
| | 428 | 48.7 | | | | | | | | | | | | | | | | |
| CNO | 361 | 45.4 | | | | | | | | | 0.0315 | 81.4 | 0.0180 | 61.9 | | | | |
| CFW | 362 | 44.2 | 0.0294 | 43.5 | | | | | | | | | | | | | | |
| | 418 | 48.0 | | | | | | | | | | | | | | | | |
| FXL | 597 | 33.5 | | | | | | | | | | | 0.0275 | 40.0 | | | | |
| FKE | 802 | 27.0 | | | | | | | | | | | 0.0301 | 53.6 | | | | |
| GVR | 413 | 42.4 | | | 0.0346 | 35.2 | 0.0273 | 52.1 | 0.0254 | 29.8 | | | 0.0155 | 82.0 | 0.0134 | 60.5 | 0.0160 | 66.5 |
| | | | | | | | | | | | | | | | 0.0164 | 70.6 | 0.0176 | 71.8 |

Table I in the form of the slope of the line in the melting region and the value of charge per unit volume at start of melting. Descriptions of the powders used are included in Table III.

Several graphs, constructed from the Greaves, Abram and Rees data, are of interest. Fig. 1 shows the variation of the minimum charge to produce melting with the chamber volume, using the data from Table IA. It is seen that the data agree quite well with a straight line drawn through the origin, indicating a nearly constant density of loading for start of melting. Fig. 2 shows the effect of the flame tempera-

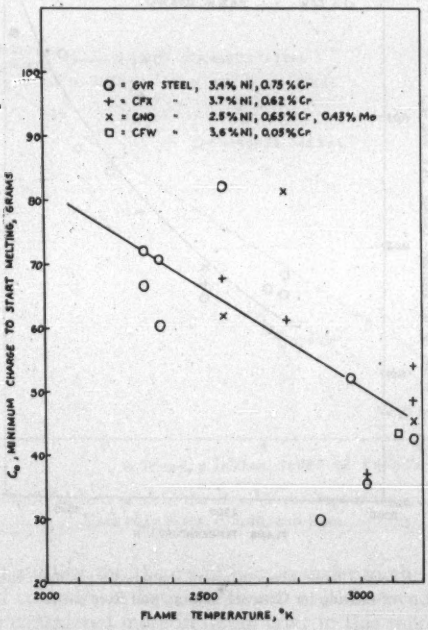



FIG. 2. Effect of flame temperature of the powder upon the minimum charge to produce melting. Data of Greaves, Abram, and Rees.

ture of the powder on the value of this minimum charge; from data given in Table IB. It is seen that as the flame temperature increases, the required quantity of powder decreases as might have been expected. Fig. 3 shows how the slope of the erosion-charge curve is affected by flame temperature, from the data in Table IB. Fig. 4 shows the effect of the melting point of the metal on the slope of the erosion-pressure

curve above the minimum pressure to start erosion from values given by Greaves, Abram, and Rees in their article. It is seen that the rate of increase of melting increases as the metal becomes easier to melt. The values for the softer metals are determined from a few firings and are not accurate. It must be noted in connection with these figures

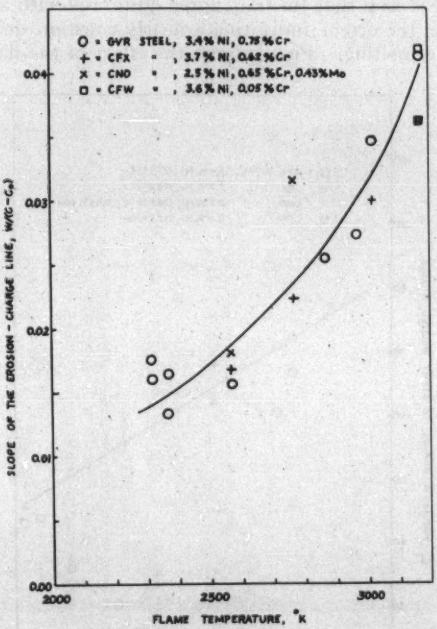

O = GVR STEEL, 3.4% NI, 0.75% Cr
+ = CFX " , 3.7% NI, 0.65% Cr
X = CNO " , 2.5% NI, 0.65% Cr, 0.43% Mo
□ = CFW " , 3.6% NI, 0.05% Cr
SLOPE OF THE EROSION - CHARGE LINE, W/C - $C_0$
0.00
0.01
0.02
0.03
0.04
2000
2500
3000
FLAME TEMPERATURE, °K

FIG. 3. Effect of flame temperature of the powder gas upon the rate of melting for Greaves, Abram, and Rees data.

that the chamber volumes are large, 400 to 3000 cc., the holes are small, and hence the time of escape is long, i.e. of order of 0.5 sec. or more.

Figs. 5 and 6 show some interesting results of the Greaves, Abram, and Rees data on tapering sections. It will be seen that as the slope increases, not only does the erosion of the taper increase, but the erosion of the downstream section increases also. These figures are of especial interest in gun design as to the taper used in the forward end of the chamber.

G. de Bruin carefully reviewed previous important theories (1), and also made several experiments (2). He used a 40 cc. closed chamber, several sizes of vents, and several types of powder. In one series of experiments, the vent was in three parts, the initial and final sections each of the same length, separated by a center section with much larger diameter hole. In all cases, the last section was most badly eroded, due apparently to the turbulent conditions produced by the central expansion section.

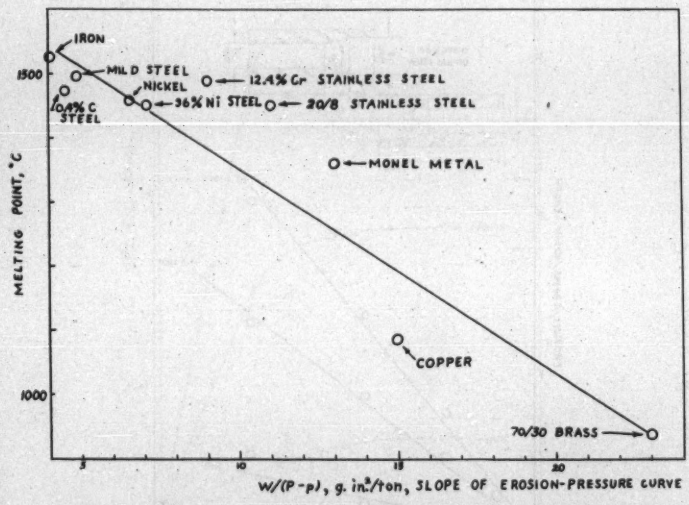



FIG. 4. Effect of melting point of the metal on the slope of the erosion curve. Data of Greaves, Abram, and Rees.

Soodak (9) studied the theory of heat transfer in the vent hole and achieved good comparison between theory and observed results. His results will be considered more in detail later in this report.

Stanton (10) in an article on jets from nozzles showed the appearance of shock waves within the jets. It is quite possible that such shock waves may cause the periodic type of attack observed by many investigators by giving local regions of higher pressure and temperature. This is particularly true as the vents in which this phenomenon is observed have constant cross section.

These several works lead to a number of conclusions about erosion which are worth reviewing briefly. The erosion of metal in guns by the hot gases produces a characteristic appearance of the metal surface.

In ferrous metals, the surface takes on a checked appearance after several rounds, while in nonferrous metals, the surface has a streaked washed out appearance. In larger caliber guns, gas leakage past the rotating band results in local areas of deep erosion which have a smooth washed-out look. Metallographic examination of the checked areas shows several layers for ferrous metals (8), beginning with one or more white layers at the surface, of martensitic structure, with lower layers

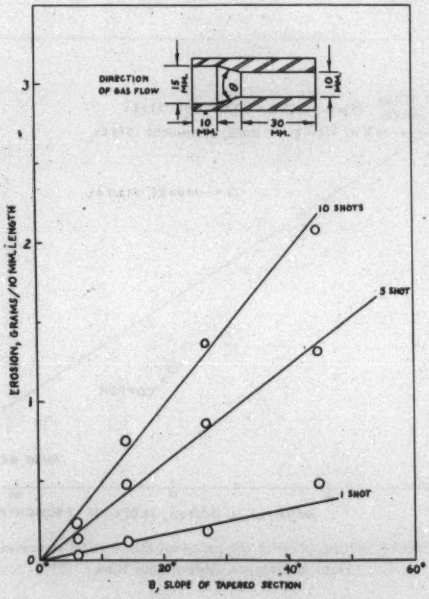



FIG. 5. Effect of slope on erosion of tapered section. Data of Greaves, Abram, and Rees for cordite powder.

of troostitic and sorbitic structure. Non-ferrous alloys show some changes in grain structure, but exhibit of course, none of the martensitic appearance. It is not clear whether the checked structure is a cause of erosion or not, but it usually accompanies it. One theory is that the checked structure results from rapid cooling of the metal surface following the heating by the hot gases.

The two main theories of erosion in guns are the surface fusion theory and the chemical reaction theory. Supporting the former theory is the relation between melting point of the metal and the amount of

erosion as observed in vents and the agreement with heat transfer theories. It appears from the work of Greaves, Abram, and Rees that the chemical reaction theory may apply in vent plugs only below some critical pressure at which melting starts, as melting seems clearly indicated above this critical value.

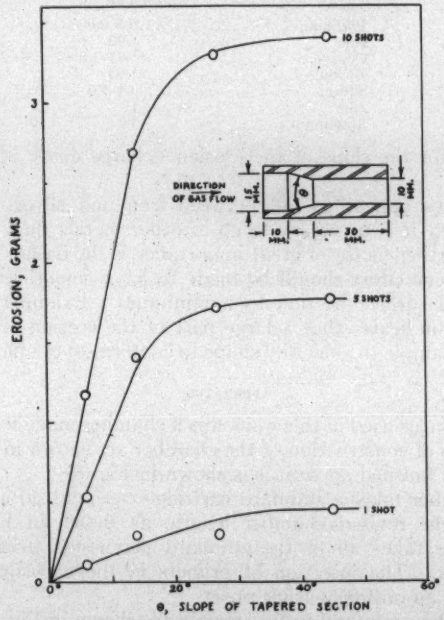



FIG. 6. Effect of slope on the erosion of the exit section. Data of Greaves, Abram, and Rees for cordite powder.

The vent plug test, either as a cylindrical plug with a hole, or as several rings of metal in series forming one tube, appears most analogous to erosion in nozzles, rather than guns. The gas velocities are quite different in the cases of guns and nozzles which should give large differences in heat transfer rates. Increasing the pressure in a vented bomb at first causes but slight erosion up to a critical pressure, $P_0$, while further increase causes a rapid increase of erosion in a linear manner. Increasing the area of the hole causes a decrease in erosion, approximately proportional to the area although the data are not consistent; this would appear to be an indication of the effect of the length of time

of contact. Increasing the flame temperature of the propellant increases the melting rate, and decreases the charge required to start melting. Increasing the melting point of the metal decreases the melting rate.

The rough order of pure metals is given in Table II, relative to pure

TABLE II.

*Relative Erosion of Pure Metals.*

| | |
|---|---|
| Platinum | 0.5–0.9 |
| Iron | 1.00 |
| Copper | 1.03–3.8 |
| Nickel | 1.60 |
| Silver | 3.4–5.0 |
| Zinc | 15 |
| Aluminum | 33 |

iron as one, for the slope of the erosion—charge curve in the melting region:

Steel alloys appear to fall between iron and silver. It may be concluded that it is necessary to go to other metals than steel and its alloys. A further factor of great importance is the design of the nozzle or vent. Every effort should be made to have smooth eddyless flow, and keep the surface friction to a minimum. Examination of vent plug sections indicates that a large part of the erosion is produced in bringing the sample to a definite shape to conform to the pattern of flow.

## APPARATUS.

The apparatus used in this work was a chamber made from a 37 mm. gun. Details of construction of the chamber are shown in Fig. 7 and a picture of the finished apparatus is shown in Fig. 8.

The chamber takes a standard cartridge case, cut off at the end to conform to the revised chamber length, as shown in Fig. 9. This cartridge case takes all of the standard percussion primers used in artillery work. The insertion of primers in the cartridge cases was performed on an ordinary arbor press.

The gage housing used in the chamber is shown in Fig. 10. This is the type of housing used in closed chamber work at the Ballistic Research Laboratory, and is modified slightly for use in this chamber by the concentric groove cut on the end. This allows a gasket to be used between this face and the bottom of the gage hole of the chamber, in place of the ring gasket usually used on the shoulder of the housing. The gage for this housing is shown in Fig. 11, and is a modification of the gage described by Kent and Hodge (4). It will be noted that one lead is brought out through the steel hemisphere at one end and through the insulated stem of the backing screw, as in the Kent and Hodge gage, but the other lead is brought out through the slot in the housing. This eliminates grounding one side of the gage to the apparatus and decreases the difficulties encountered in obtaining a record free from outside electric interference.

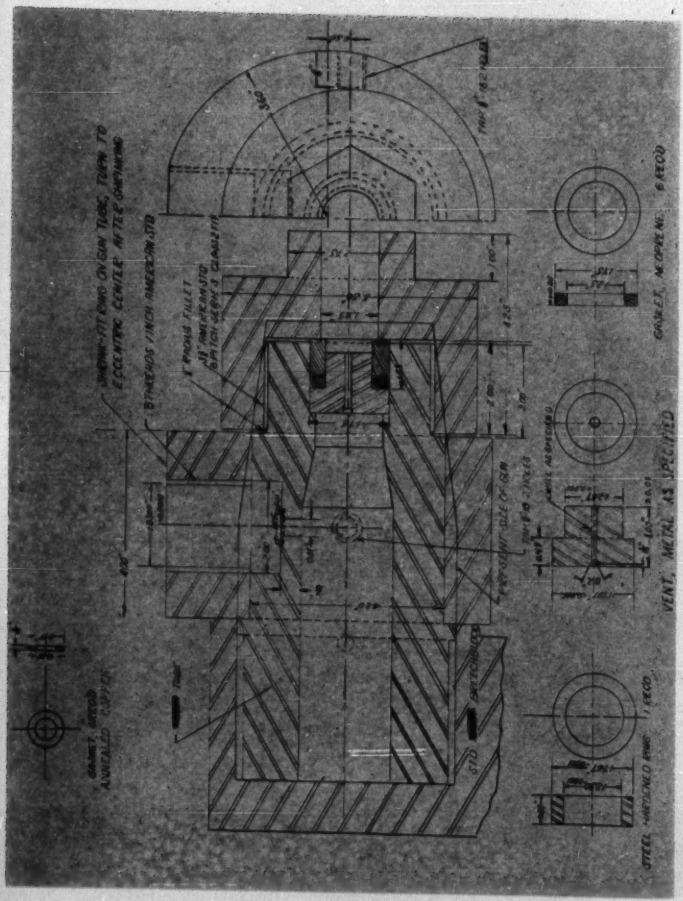



FIG. 7. Detail drawing of erosion vent plug apparatus.

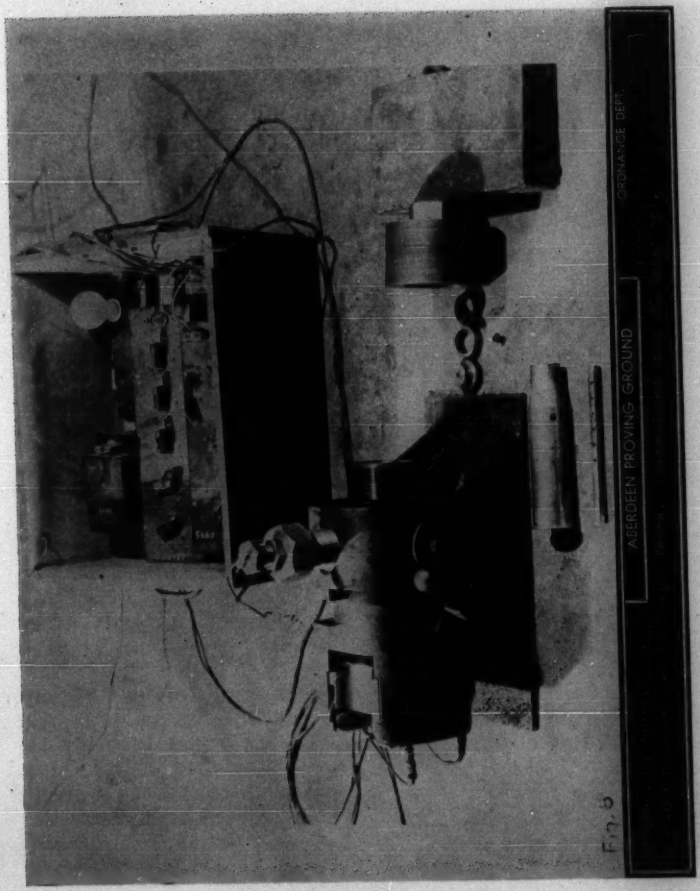



FIG. 8

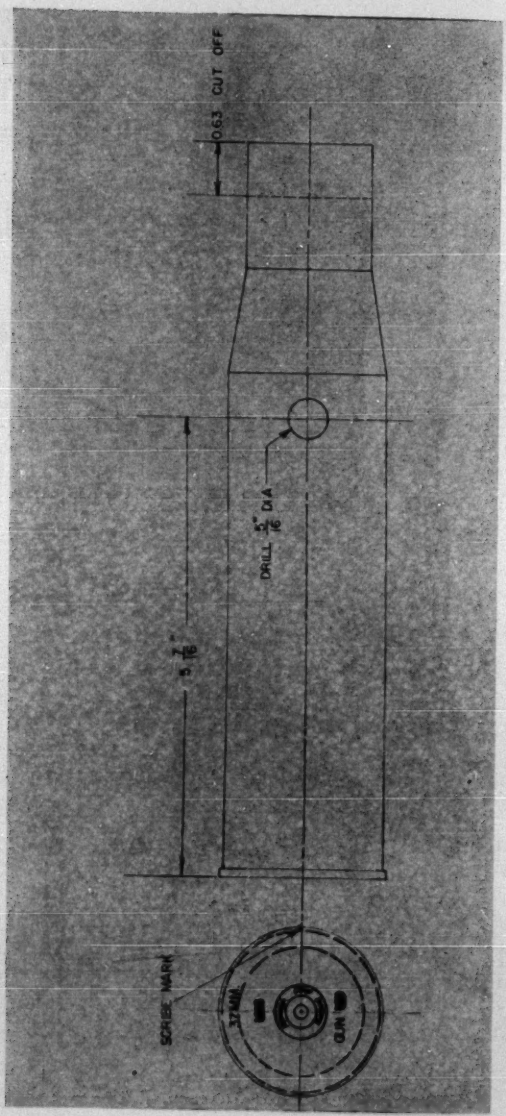



FIG. 9. Cartridge case modified to fit blowout chamber.

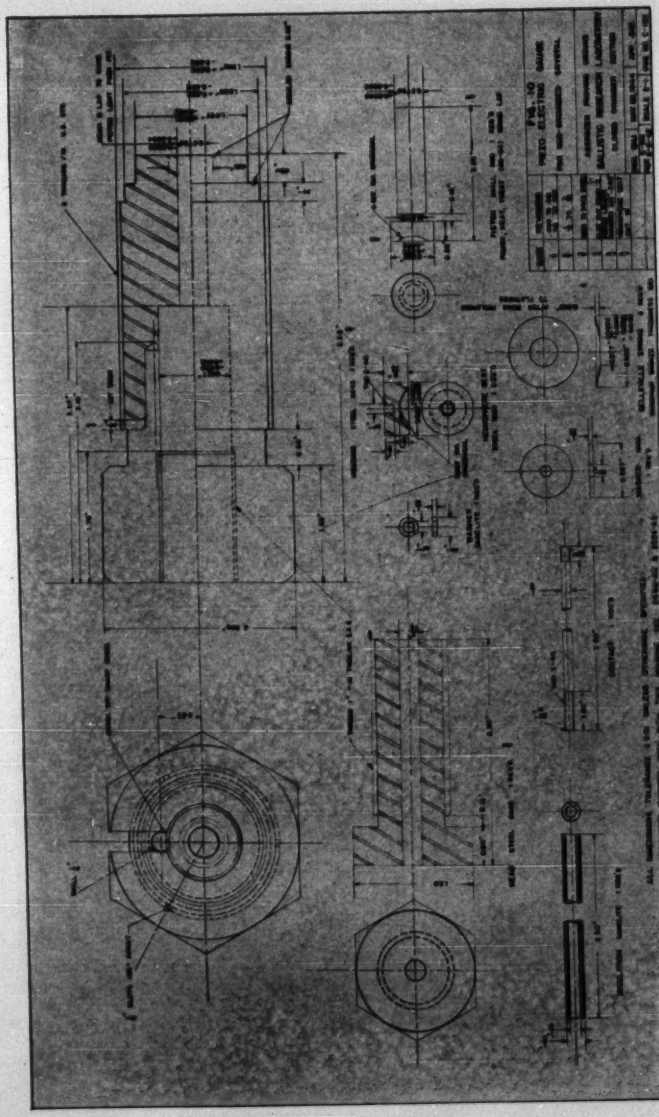


FIG. 10

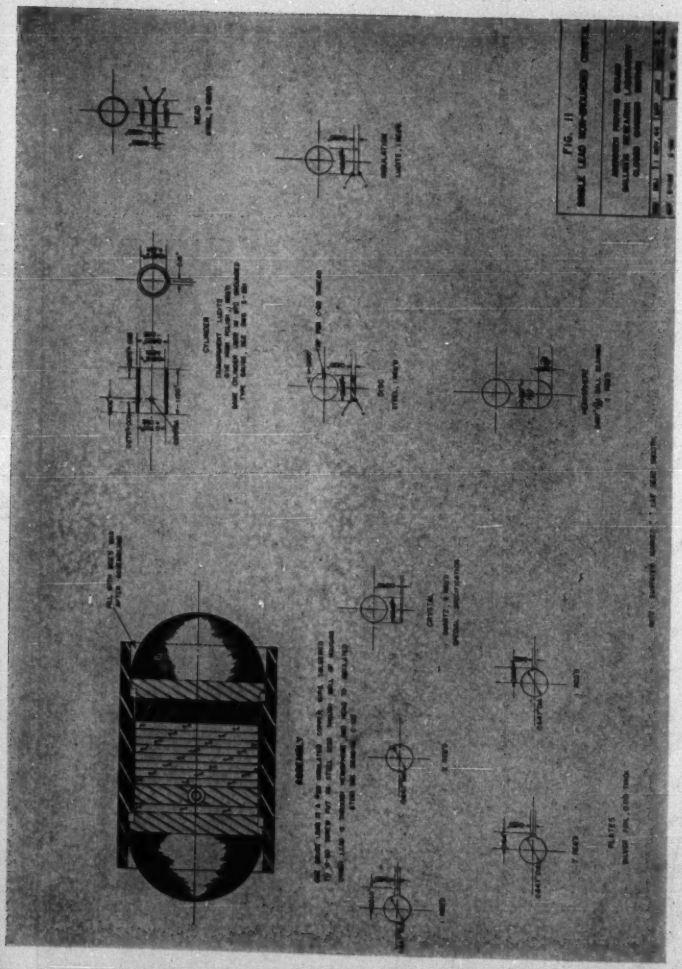


FIG. 11

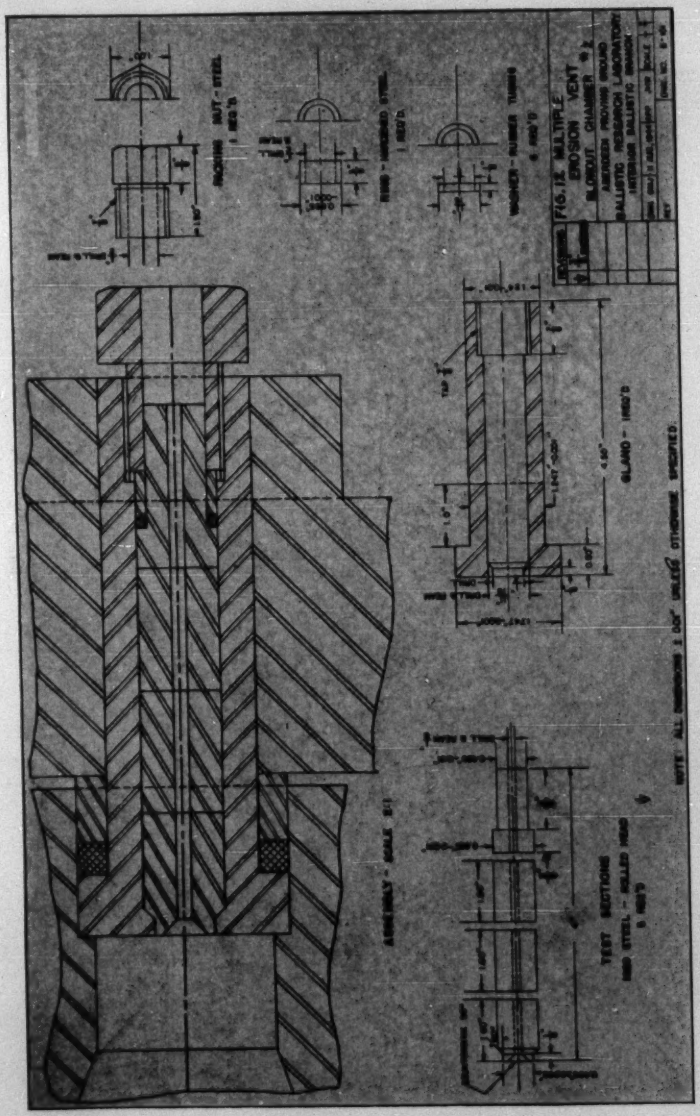
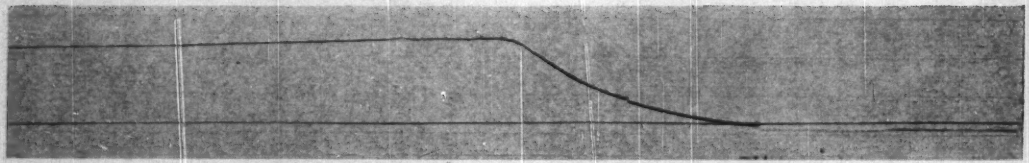
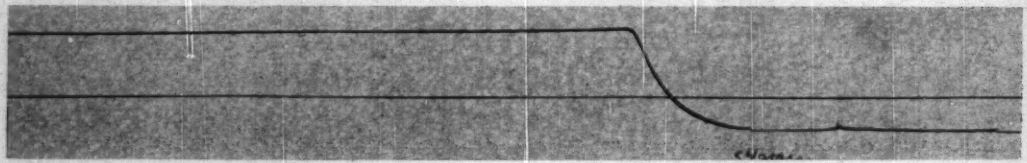


FIG. 12. MULTIPLE
EROSION VENT
BLOWOUT CHAMBER
ASSEMBLY - SCALE
TEST SECTIONS
GLAND - MSS
NOTE: ALL DIMENSIONS IN INCHES UNLESS OTHERWISE SPECIFIED.

FIG. 12



(a) Round 1, August 3, 1944, 15 grams of Lot 8108 powder with the 54-grain primer
$P_{max.}$ = 8,760 psi., burning time = 0.073 sec.



(b) Round 3, August 3, 1944, 45 grams of Lot 8108 powder with the 54-grain primer
$P_{max.}$ = 26,180 psi., burning time = 0.063 sec.

FIG. 13. Records taken on the blowout chamber fired as a closed chamber. It will be noted that the obturation is much better in (b) than in (a) due to the higher pressure used. The burning time is the time from the electrical activation of the solenoid which pulls the trigger to $P_{max.}$

The gun is fired by a solenoid connected to the trigger. The firing circuit contains a coil of a few turns next to a similar coil in the gage circuit, which induces an e.m.f. in the gage circuit upon firing and places a "kick" on the drum camera record. The firing switch, a double pole single throw type, has several contacts so that the drum camera shutter circuit is closed just before the trigger circuit.

Fig. 12 shows the multiple type of erosion vent, which allows the factor of length of vent to be considered. For both of the types of erosion vents, obturation is obtained by the use of an unsupported area type of seal. In the multiple vent assembly, a small amount of gas leaks around the outside of the first block and back into the vent, giving a small amount of erosion in the process.

In use, the cartridge cases are primed, a weighed charge placed in the cartridge case, and the case inserted in the breech. The erosion vents are weighed and inserted in the chamber. The electrical circuits are checked and finally the breech is closed and the charge is fired. The erosion vent is then removed and carefully cleaned with soap, water, and a brush, then rinsed in acetone, dried and weighed. The balance used in the work has a sensitivity range as follows:

| Wt. on each pan, grains | 0 | 500 | 1000 | 2000 |
|---|---|---|---|---|
| Wt. to give deflection of pointer of one scale unit, grains | 0.0053 | 0.0059 | 0.0063 | 0.0070 |

The reproducibility is indicated by the following three separate weighings of a sample, 197.119, 197.118, 197.118 grains. The weights determined are therefore believed good to $\pm 0.001$ grain or $\pm 0.0006$ gram.

The apparatus as assembled for this work has proven durable and, due to the breech mechanism, capable of rapid operation. In repeated firings, as many as 50 rounds per eight hour day have been accomplished by a two man crew. Another advantage is that the cartridge case holds whatever residue is left after firing, so that the chamber itself remains clean. This is particularly useful in black powder work where a large amount of solid material is left after firing.

A check on the obturation of the chamber was made by firing the chamber as a closed chamber. To do this, the single erosion vent was replaced by a solid plug. Typical records using this type of closed chamber are shown in Fig. 13. It will be noted that the cartridge case obturates at a fairly low pressure. However, for the low pressure shots, below 10,000 p.s.i., the application of pressure was slow, and the obturation not as satisfactory, particularly at the gage hole. The solution for such cases is to file the cartridge case thin around the gage hole. For normal work, this is not necessary, and only the addition of several layers of cellulose tape over the gage hole is required.

*To be continued*

## NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

### SHIELDING PRINCIPLE PROVIDES ELECTRONIC MICROMETER.

The principle that the field surrounding a coil fed with alternating current will induce current in an adjacent coil and that the amount of current thus induced can be controlled by placing a shield or a low-resistance conductive medium at various distances from the latter coil, is employed to make a linear reading device for use as an electronic micrometer. The shield is placed not between the primary and secondary coils, but adjacent to the latter. Its distance from the secondary coil determines the amount of energy produced in this coil.

The new device, developed by M. L. Greenough of the National Bureau of Standards, was primarily designed to afford a means for measuring thickness of the oil film in the bearings of a large Navy turbine shaft. The device has a number of important applications: as a micrometer, a phonograph pick-up, a microphone, and for similar purposes.

The electronic micrometer designed at the Bureau utilizes the fact that radio frequency energy radiated from a coil is at zero at the surface of a perfectly conducting shield adjacent to that coil. This phenomenon occurs because eddy currents are set up in the shield by the field of the radiating coil, and these eddy currents set up an opposing magnetic field at the surface of the shield. The opposing field exactly cancels the incident field at the surface of the metal plate. Theoretically a pick-up coil of zero thickness applied at the surface of the shield would receive no energy. It is, however, impossible to design a coil of zero thickness. Therefore compensation for the necessary thickness of the coil has been included in the design.

When the pick-up coil is moved away from the shield, in the direction of the radiating coil, it picks up a certain amount of energy because the radiated field becomes stronger while the field set up by the currents of the shield becomes weaker due to the change in distance. This condition becomes more marked as the distance between the pick-up coil and the shield increases. This is true whether the distance between the pick-up coil and the radiating coil decreases or remains unchanged.

Because the metal background is not a perfect conductor and because the coil has measurable thickness, a minimum reading is obtained when the pick-up coil is in contact with the metal background. This condition is corrected by the addition of a third coil which permits a zero reading to be obtained.

* Communicated by the Director.

The radiating coil is fed a high frequency current. When the micrometer is held at some distance from any metallic object, the field from the radiating coil induces voltage in the secondary (or pick-up) coil, and this induced voltage is measured either on an oscilloscope or by an alternating current meter. The linear indication of the change in distance between the micrometer and the metal background is indicated on the meter or oscilloscope.

This principle can be employed in a variety of ways. Most obvious, perhaps is its use as a micrometer. In this application, the coil assembly is mounted on a movable shaft in such manner that it can be caused to approach or recede from a metallic plate. The material to be measured is placed between the pick-up coil and the metallic plate and is pressed lightly between them. When the material is removed, the amount of current generated in the pick-up coil is an indication of the thickness of the material which occupied the space. The meter indicating the output of the coil is calibrated, not in current or voltage, but in thousands of an inch in order to give a direct measure of distance or thickness.

Capacitance micrometers, with which measurement is made of the thickness of a non-conducting film separating the micrometer from a conductive background, are well known. It is impossible, however, to use micrometers of this type where the conductive background is either inaccessible or cannot be accurately defined. Similarly, inaccuracies are likely to be introduced because of changes in the dielectric constant of the insulating film covering the metallic backing.

When the electronic micrometer was used to measure the displacement of a turbine shaft in its journal, four of the devices were spaced equally around the turbine shaft. This arrangement is so sensitive that a deflection of 1/100 inch of the center of a six-inch shaft provides a two-inch deflection of the center spot of a cathode ray tube. The micrometer is about 1/2 inch in diameter by 1/4 inch in length and is able to measure distances from zero to 0.02 inch. Readings to 0.0001 inch are easily obtained. The indication on a meter is linear to within a fraction of one per cent.

When the principle is employed in a phonograph pick-up, the vibration of a flat-plate armature fastened to the needle causes a change in the position of this armature with respect to the pick-up coil. This causes alternation in the output of the pick-up coil, and these electrical fluctuations may be rectified and fed into an amplifier for reproduction. By selection of suitable frequencies, the output of the pick-up coil may be high frequency fed directly into the intermediate frequency stages of a superheterodyne phonograph-radio receiver in any of a variety of ways. Tests of the circuit indicate satisfactory operation in receivers using a 450-kilocycle intermediate frequency.

When the electronic micrometer is used as a microphone, vibrations adjacent to the pick-up coil are created by a metallic diaphragm, and the

movement of this diaphragm causes fluctuations in the output of the pick-up coil. The action is similar to that of the device used as a phonograph pick-up. With a slight modification, the device may be used as a thermometer. A strip of bi-metal of convenient length is so mounted that it extends in a path parallel to the end plane of the pick-up coil, positioned closely adjacent to that coil. As the bi-metal bar bends in accordance with heat, its free end is brought closer to or farther from the pick-up coil and an indication is given on a meter calibrated in degrees.

Another application of the device is the tachometer or speed indicator. In this case, the end plate of a flyball governor may be so mounted as to approach or recede from the pick-up coil as the speed of rotation of the governor increases or decreases. Still other applications of the electronic micrometer are feasible. It is obvious that it can be appleid to any use where the variation in distance between the coil and a conductive plate may be used to produce an electric current which will vary in linear manner in accordance with the change in distance.

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## "WORKABILITY INDEX" OF FIRECLAY REFRACTORIES.

During the past two decades, fireclay plastic refractories have gained wide use in industry for such applications as furnace linings, forming into refractory shapes, and quick repair jobs. An important requirement of this commodity, therefore, is that it flows without cracking while being rammed into molded shapes or furnace walls and yet does not deform under its own weight during subsequent drying.

Because of the numerous variables in the determination of the workability of fireclay plastic refractories which affect their acceptability, the Refractories Laboratory of the National Bureau of Standards conducted an extensive investigation of the reliability of the test method now accepted as standard. Results of tests on nine plastic refractories by R. A. Heindl and W. L. Pendergast have provided basic data for use in revision of the method and techniques of testing such plastics that will furnish a truer indication of workability, as a basis for their acceptance or rejection.

A measure of the facility with which plastic refractory material can be rammed into place as determined with a specified sand rammer has been designated "workability index" by the American Society for Testing Materials. The instrument used for determining the index, the "sand rammer," is so called because of its use in the testing of foundry sands. The first step in the ASTM test of plastic refractories involves the molding of a standard 300-gram cylindrical test specimen with 20 impacts (10 on each end) of a 14-lb. weight. Immediately after removing the specimen from the mold, and measuring its length, it is subjected to three additional impacts after which it is again measured.

The plastic deformation computed from the difference in lengths and expressed in per cent. is the workability index. The specified permissible range of this index is from 15 to 35 per cent.

The first of the variables investigated by the Bureau was the mounting for the sand rammer. The results obtained with four types of mounting indicate that the rammer should be solidly mounted on a non-vibrating stone or concrete block in order that a minimum amount of the work performed would be absorbed by the support. Lubrication of the mold not only improved the appearance of the test specimens, but decreased the workability index as much as 20 per cent. This was due to the decrease in friction between the wall and the plastic refractory—especially when the moisture content was low.

Obtaining a cored sample with a steel tube instead of a "grab sample" gave information on the extent of moisture variation in the plastic from top to bottom and across the 200-lb. container. For example, one plastic had an over-all moisture variation from 8.1 to 9.9 per cent. with an average of 8.4 per cent. The method of obtaining the sample as well as that of filling the mold resulted in pronounced difference in the magnitude of the workability index. The interior of the steel mold for forming the test cylinder should be machined smooth and a $\frac{1}{4}$-inch steel disc, made to fit the interior snugly, placed at each end of the test specimen during forming. The use of the discs prevents featheredging of the specimen and possible loss of material.

The 20 impacts specified in the ASTM method of test for molding a plastic refractory do not always result in the specimen reaching maximum bulk density. Some of the plastic refractories investigated by the Bureau reached their maximum bulk density (or minimum height) before 20 impacts whereas others did not reach the same condition until 70 impacts. The further the specimen is from the maximum density the greater the possibility that the workability index may be affected by disruptive failures rather then by plastic deformation. The index, therefore, may be misleading since it would indicate a workability higher than warranted. For instance, using the standard test method, an index of 24 was obtained for one of the specimens, signifying acceptable material. However, after 70 impacts the index was 13, indicating that the material should be rejected, which should have been the case initially since it was too stiff for satisfactory use.

As a result of the investigations by the National Bureau of Standards, it has been recommended that the workability of a plastic refractory be based on the amount of work required to reach maximum bulk density rather than on a deformation test. In addition, the findings also indicate the need for the standardization of the method of test.

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## NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

**Standardization of Radioactive Phosphorus.**—T. ENNS. Radioactive phosphorus samples have been measured with an air-filled ionization chamber and compared with a uranium-oxide standard. The calculated activity of the phosphorus has then been compared with that calculated from Geiger-counter measurements.

The ionization chamber gives equal ionization currents for high energy beta particles of varying energies. It has been shown experimentally that in an identical ion chamber the beta particles of radio-lead (maximum energy 1.12 MEV.) and those of $UX_2$ (maximum energy 2.32 MEV.) produce equal ion currents for equal numbers of emitted particles (1). This result is to be expected from the equations for specific ionization (2).

The uranium in the uranium-oxide standard is in equilibrium with its decay products $UX_1$ and $UX_2$. The $UX_1$ beta particles are absorbed by the ion aluminum chamber window and the cellophane sample cover so that only the $UX_2$ beta particles are measured. The number of $UX_2$ disintegrations is calculated from the weight of uranium in the standard.

### EXPERIMENTAL.

The ionization chamber ion collector is connected to an electrometer circuit using a Victoreen VX41 electrometer tube and a galvanometer output meter. The electrometer sensitivity of this circuit is 60,000 mm. per volt. Readings are made by removing the ground connection from the collector and timing the change in galvanometer reading.

This apparatus can detect activities as low as .0001 microcuries, or approximately 100 disintegrations per minute.

Readings were made by placing the samples on the one-inch-diameter ion chamber window. Both the uranium-oxide sample and the phosphorus sample were mounted on identical thick glass depression slides. The circular depressions had a .75-inch diameter. The samples weighed less than 20 mg. and were fairly evenly distributed over the surface of the depressions, hence sample self-absorption is negligible.

The Geiger-counter measurements were made with a small counting tube surrounded by lead. The counting window was 5 mm. in diameter and the phosphorus sample was placed 10 cm. from it. Corrections were made for absorption in the air and counter walls. Sample activity was calculated from the counter geometry.

RESULTS.

The phosphorus activity as measured by the ion chamber and calculated from the uranium-oxide standard was .0223 microcuries. The activity of the same sample as calculated from the Geiger-counter measurements was .0245 microcuries. The discrepancy may be partly due to back scattering from the sample mounting in the Geiger-counter measurements.

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## BOOK REVIEWS.

MECHANICS OF MATERIALS, by Philip G. Laurson and William J. Cox. 2nd ed. 422 pages, drawings, 14 × 22 cms. New York, John Wiley & Sons, Inc., 1947. Price $4.00.

Method of presentation of technical subjects to students is of extreme importance. This fact has been recognized for a considerable time and the more progressive teachers and textbook authors are continually striving for improvement of methods. Topics are separated or combined, some may even be eliminated, their order may be changed, the coupling between them may be improved and the actual wording may be changed, all according to the dictates of experience and good practice. The book at hand was originally published in 1938 and used extensively since then. The experience thus gained has accumulated and been applied in this, the second edition.

The purpose of the text is to prepare the student for an eventual clear understanding of machine and structural design. The method employed to do this is the feature of the second edition. There are twenty-two chapters. After an introduction, they define the various mechanical properties of materials, and discuss how they may be determined and their importance. Subsequently the topic of stresses is taken up covering axial loads, torsional stress, stresses in beams, etc., this topic entering into treatments throughout the work. Considerable space is given to beams and columns of the same and different materials, different kinds of joints including riveted and welded joints, and some space is devoted to thick walled cylinders subject to internal and external pressure. The method used in presentation is to avoid extreme conciseness and substitute therefor clear statements with ample explanations and a free use of solved illustrative problems. There has been no sacrifice in this second edition in the amount of work necessary to achieve results. A casual glance through the book reveals the authors' belief in exercise in order to impress. The plan is to instruct for an interval, then solve exercise problems, more instruction, then solution and so on. The exercise problems therefore are as important as the text. General problems can be found at the end of each chapter, and the last chapter consists of comprehensive problems. Appendixes contain data on centroids of areas, the moment of inertia of a plane area and unusually complete tables for the solution of all problems. The use of a steel handbook may be dispensed with. A subject index is in the back.

The book lays down a course of study giving adequate coverage with clarity and employing modern methods. It is flexible so as to fit into various academic situations and requirements.

R. H. OPPERMANN.

RESISTANCE OF MATERIALS, by Fred B. Seely. 3rd ed. 486 pages, drawings, 14 × 22 cms. New York, John Wiley & Sons, Inc., 1947. Price $4.00.

The subject of the resistance of materials has been much to the fore in recent years, brought about in part by the wider use of light weight metals and high strength metals, the more extensive use of welded connections, the use of metals at very low and very high temperatures, etc. The means of indicating satisfactory materials for use at room temperatures under static loads and uniformly distributed uniaxial stress may be quite unreliable for indicating whether material is satisfactory for use in another set of conditions involving quite different combinations of temperature, state of stress, distribution of stress, speed of straining, and strain aging proporties of the materials. Most of this is beyond the field of an elementary textbook, but the trends have root there. This third edition of the textbook "Resistance of Materials" has been reset and to some extent reflects these trends.

As in the previous edition, there are two parts. Part I is contained in 328 pages covering elementary topics. It begins with treatments on stress and strain, thin walled cylinders and spheres, and progresses through topics of riveted and welded joints, stress and strains caused by torsional loads, transverse loads and stresses in beams. Then there is taken up the determina-

tion of relations between the elastic deflection of a statically determinate beam and the loads, the stiffness of the material, and the dimensions of the beams, when the beam is loaded in various ways. This is followed by coverage of statically indeterminate beams. The principle of superposition is illustrated in determining the normal (tensile or compressive) unit stress at a point in a member when the member is subjected to combined axial and bending loads, and also in determining the shearing unit stress when a member is subjected simultaneously to a central shearing load and torsional loads. Compression members, columns, theories of failures, repeated loads, fatigue of metals, impact and energy loads are subsequent topics of Part I.

Part II is devoted to special topics further advanced but within reach of those who have studied Part I. Each of them is independent of the other. The conjugate beam method of determining the deflection of statically determinate beams and of determining the reactions on statically indeterminate beams is discussed. Likewise a space is devoted to the limitations of the flexure formula as applied to a beam having a cross section containing only one axis of symmetry. The analysis of the stress in a straight beam loaded in a plane of symmetry developed in Part I is extended to include a straight beam with unsymmetrical loading, and a curved beam loaded in a place of symmetry. Other of these topics include flat plates, thick walled cylinders, composite beams and elastic vibration of load resisting members. Appendix I is devoted to properties of an area. Appendix II gives properties of rolled steel sections. At the end there is a subject index.

The book is a clear cut exposition with illustrative problems, exercise problems, and review questions. The flexibility afforded by Part II adds greatly to its value as a text for students and reference work for practicing engineers.

R. H. OPPERMANN.

INTRODUCTION OF MATHEMATICAL STATISTICS, by Paul G. Hoel. 258 pages, drawings, 14 × 22 cms. New York, John Wiley & Sons, Inc., 1947. Price $3.50.

This is a fascinating, promising, and rapidly developing subject that finds uses in science and economics wherever data can be obtained from a repetitive operation or when it may be possible to conceive of a repetitive operation. Experience indicates that many repetitive operations behave as though they occurred under essentially stable circumstances. Under such circumstances, it is often possible to construct a satisfactory mathematical model of the repetitive operation to study properties of the operation and draw conclusions concerning it. Such models often prove to be useful even though the operation is not highly stable.

The book at hand is an introductory course designed for two semesters. Elementary calculus is a prerequisite. It may be divided into two parts, the first being largely concerned with the theory of certain classical large-sample methods in statistical theory. These chapters have been arranged according to the number of variables being studied. At the outset, frequency distributions of one variable are considered and this is followed by a study on mathematical work with theoretical frequency distributions which represent actual distributions. This covers treatments on general distribution functions, basic rules of probability, binomial distribution and multinomial distribution. A similar plan is followed in treating with frequency distributions of two variables and more than two variables, except that in the latter the study of the theoretical model is dispensed with because of complications that extend beyond the realm of the book.

The second part of the book begins with small sample distributions where it is usually assumed that the basic variable is normally distributed. This is succeeded by a non-parametric methods discussion, not involving the estimation of parameter values of a distribution function. Testing Goodness of Fit involving the testing of the compatibility of a set of observed and theoretical frequencies and Testing Statistical Hypotheses, including two logical principles for selecting the proper test, are later chapters. The last chapter of the book deserves special mention because it refers to the science student. Often, experimenters seek statistical assistance when experiments fail to produce anticipated results. It is pointed out here that if due appreciation were made of statistical principles in planning experiments much of this would be

avoided. The statistical design of experiments is considered in this chapter from point of view of validity and efficiency. Although an experimental design that does not yield valid results may be considered inefficient, attention is directed in the convenience of distinguishing between these two concepts because a valid design need not be an efficient one. In the back of the book are tables and a subject index.

The book represents a comprehensive introduction to the subject within quite clearly defined limits. It provides a good foundation for the student and is a modern reference work on fundamental methods.

R. H. OPPERMANN.

TALKS ABOUT STEELMAKING by Harry Brearley. 236 pages, illustrations, 15 × 24 cms. Cleveland, The American Society for Metals, 1946.

As the title of this book indicates, it consists of chapters devoted to the processes and features of steel making. The order is only roughly in sequence and any chapter can be selected without the background of previous chapters. The tenor of the presentations is practical rather than technical.

The first two chapters deal with what is termed "Beginnings" and refer to chemical analysis and the use of the microscope in the laboratory. This is followed by a chapter on molten steel and the defects of ingots and castings. A considerable portion is devoted to melting processes which describes the history and the technique of the Huntsman, Bessemer, Siemens, Thomas and Electric processes. This section is particularly interesting for its descriptiveness. Later topics are forging, testing, notch fractures, specifications, and clean steel including tests for undesirables and non-metalics. The latter part of the book deals more in generalities and peculiar worthwhile angles of views of the art of steel making. Questions are examined which include "Why the covering of slag?", "What is it and where does it come from?". Later, the complaint of the customer is examined in an effort to learn to make the more desirable steel. A matter-of-fact talk is given to renumeration in the steel trade and a final chapter on "Scrap-alurgy" which is of corse the utilization of scrap.

The book is one principally for the worker in the steel mill but it has much information for the layman only mildly interested in steel making.

R. H. OPPERMANN.

TELEVISION, edited by Alfred N. Goldsmith, Arthur F. Van Dyck, Robert S. Burnap, Edward T. Dickey, George M. K. Baker. Volume III (1938–1941) and Volume IV (1942–1946). Approx. 500 pages, drawings and illustrations, 15 × 23 cms. New Jersey, Radio Corporation of America, 1947. Price $2.50 each. Cloth bound $1.50 each.

These two volumes consist of many excellent papers on the subject of television, selected by the joint editors. In volume III the papers are presented in four sections; pickups, transmission, reception and general. Volume IV consists of six sections, namely pickup, transmission, reception, color television, military television and general.

Through constant research in the advancing field of television many papers and books have been written and it is by publishing these two volumes that an excellent collection of papers has been compiled to show the advance of television through research. These two volumes supplement Volumes I and II which were published before the war period. Though there was quite some delay in the appearance of these last two volumes the efforts of the editors have not been in vain. From a large collection of papers written during the period 1938 to 1946 a very careful selection was made, published in clear type and illustrated in good form.

Today television and television broadcasting is a practical reality. These papers show that through research great strides have been made in a short time.

P.

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## CURRENT TOPICS.

**Underground Industrial Plants have Limited Possibilities.** (*Industry and Power*, Vol. 52, No. 4.)—If atomic power is to be the predominate weapon of the world, the only hope of security of any nation big or small is the control of all fisionable materials by a world organization and free access for inspection of research institutions and manufacturing concerns. Pending the realization of that dream, underground industrial plants merit at least some consideration.

Ages ago man found refuge in caves and crevices. Not only was he protected from the elements, but, with a reduction in the angle of approach, he was not so vulnerable to attack from his enemies. We do not have sufficeint caves to house the millions of people now inhabiting the earth, and in the light of present developments our artificial shelters look inadequate. So far the only defense proposed against atomic bombs is distance and mass. Without doubt some of our industries are giving consideration to going "in the hole" to place sufficient mass between the plant and point of attack. Fortunately such a move is not altogether financially unsound.

Many large buildings have been erected that have basements with 4 to 6 floors below street level. The extra space made available did not cost appreciably more than the convenitonal and upkeep has not been as high. Once inside the building people do not seem to notice whether they are above or below ground level, as everything is oriented with reference to some such place as the elevator, escalator, lunch room or bar.

Aside from the protection from sudden destruction, being underground offers some other distinct advantages, namely; better temperature control, less maintenance, and possible use of gravity flow for production lines. To offset these gains the number of disadvantages include: cost and difficulty of construction, year round mechanical ventilation, elevator service for large number of employes, psychological reaction of workers, sound control, and restricted expansion.

R. H. OPPERMANN.

**Cocooning Aircraft.**—(*Refrigerating Engineering*, Vol. 52, No. 5.) High relative humidity puts curls in some people's hair and it is desirable for loading explosives but, generally speaking, it is a condition to be avoided. Moisture carried by the air corrodes metals, rots fabrics, spoils food, and accentuates respiratory diseases. In fact moisture-laden air accelerates the deterioration of most man-made products. The Army Air Forces, in its program of long-time storage of aircraft and other equipment, found that unless moisture could be barred from the interior of planes and instruments there was little hope of preserving this equipment in serviceable condition for any length of time.

To seal airplanes effectively against the weather, engineers at Wright Field, headquarters of the Air Material Command, have now perfected the cocooning of airplanes, completely sealing a ship as large as a B-29. Sprayable plastic which, when dry, can be stripped off like tangerine peeling is used as the storage coating for planes, engines, and equipment such as machine tools.

Before application of the protective coating, sharp corners, edges and protuberances are padded with suitable material to prevent puncturing the coating which has a tendency to shrink as it dries. To provide a base for the spray over large openings, or when the contour of an item is not to be followed, tape is criss-crossed over the opening and a webbing coat is applied. This webbing coat resembles a cobweb and is of sufficient strength and density to allow application of the first spray coat as if it were a solid surface.

The first spray coat is a strippable plastic which provides the initial moisture barrier, adheres closely to the contour being sprayed and is easily removed. To further reduce the moisture vapor transmission rate, a second coat of an asphaltic compound is applied, and a third coat of asphaltic compound to which aluminum flakes have been added further reduces the moisture vapor transmission rate and also reflects the sun's rays and thus helps in maintaining low temperatures inside the airplane.

R. H. OPPERMANN.

**Electronic Crystal Clock.**—(*Electrical Engineering*, Vol. 66, No. 4.) The only continuous time signal service is provided to the world by the National Bureau of Standards. One or more of the broadcast frequencies (5, 10, and 15 megacycles per second and 2.5 megacycles at night) is being used continuously. A crystal clock, utilizing electronic circuits instead of the conventional clock mechanisms, has been developed to insure accuracies to within a microsecond for use in navigation, seismology, and geological surveys. The flawless quartz crystal, the heart of the circuit, has a resonance frequency of approximately 100,000 or 200,000 cycles per second, and is sealed in a glass or metal enclosure to insure against variations in pressure and humidity.

The crystal oscillates continuously and the resulting stable frequency is divided with no loss of accuracy to 60 cycles per second. This 60-cycle frequency supplies power to a synchronous motor which, through gear trains, drives contacts that give intervals of 1 minute, 5 minutes, and 30 minutes to control the automatic announcement equipment of the transmitters. The motor also operates a 1-second contact which causes a very accurate seconds pulse to be broadcast.

The absolute accuracy of the frequency of the crystal oscillator is a few parts in 100 million. Although the seconds pulses are obtained by exact division of the quartz plate frequency, phase shifts and other difficulties decrease its accuracy to one part in one million.

The absolute time is supplied by the Naval Observatory. The broadcast signals constantly are compared with the absolute time and extrapolations of the data made to correct the broadcast signal. The equipment used to compare the various crystal clocks measures accurately a rate of change equivalent to one second in 50 years.

R. H. O.